# Bus User Behavior in Multi-Route Corridors

by

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Submitted to the Department of Civil and Environmental Engineering
in partial fulfillment of the requirements for the degree of

Master of Science in Transportation

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 2013



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## Abstract

Multi-route corridors are a common feature of bus networks. In these corridors, passengers select between a set of parallel routes. Understanding how passengers make these decisions can help better measure passenger experience and inform network and service planning. This thesis develops three methods for characterizing passenger behavior based on automatically collected data. The first is an empirical analysis relating bus arrivals to bus ridership on each route. The second is a probabilistic model that infers passengers' route choice strategies based on the headways that preceded their bus boarding. The third method is a panel analysis of individuals' stop and route choices over time. These methods are applied to two corridors in London, one that has only local service and another that has both local and limited stop service. On the local-only corridor, the analysis infers that the majority of passengers board the first bus that serves their destination. On the corridor with limited stop service, many passengers opt to wait specifically for the limited stop service route. This boarding strategy is increasingly prevalent as the length of the bus trip increases. Passenger behavior was also found to be affected by crowding, passenger experience on the corridor, and access to real-time information.

In addition to the analysis of automated data, this research includes a web-based survey of users of the limited stop corridor. This survey demonstrates the viability of web-based surveys for collecting detailed information about passenger behavior on a large scale. The survey data shows that passengers' route choice strategies are influenced by factors including trip length, trip purpose, respondent income, use of countdown information, attitudes towards crowding, waiting, and walking, and levels of risk aversion.

The thesis relates the analysis of passenger behavior to a set of recommendations for multi-route corridor planning. The advantages and disadvantages of corridor-level scheduling and operation are discussed, and service configuration changes for the limited stop corridor are proposed. Given the prevalence of multi-route corridors and the variety of passengers' route choice behavior within them, the incorporation of an understanding of passenger behavior into network and service planning has the potential to improve passenger experiences on bus networks.

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# Acknowledgments

I would like to thank my advisors, Haris and John, for all the guidance, feedback, and encouragement. I would also like to thank Nigel, Fred, and Mikel for providing additional advice, whenever I needed it. I am appreciative, as well, of all of the CEE staff for helping everything go smoothly.

I am thankful for the support of TfL, and in particular for the assistance and expertise of Rosa McShane, Alex Phillips, and John Barry. I would also like to thank Duncan Horne as well as Clara Barrington and her Customer Research team for their help with the distribution of the online survey.

A huge thank you is due to Laura for making me laugh, answering my questions, cooking me many delicious dinners, and generally putting up with me, all day, every day. I also owe a big thank you to Gabriel, who taught me so much when I was new to transportation, who is always willing to answer my questions, and whose programming expertise helped make this thesis possible. For great company at work each day, thank you to Yonni, Meisy, Dom, Jamie, and everyone else in the Transit Lab.

Finally, a sincere thank you to my parents and sisters for their love and for their confidence in me. And especially, to Nonna, for coming all the way across the country to watch me graduate.

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# Chapter 1

# Introduction

In dense bus networks, multi-route corridors are common. In the context of this thesis, a multi-route corridor is defined as any instance in which two or more bus routes follow the same geographic trajectory for a significant distance. This thesis seeks to understand the behavior of those passengers who board and alight from buses within the multi-route corridor. This behavior is characterized by the strategy passengers use to select a bus route from the routes that serve their destination.

First, the thesis develops three methodologies for identifying passengers' strategies. The strategy identification methods are applied to two multi-route corridors in London: one has only local routes and the other has both local routes and a limited stop service route. Each of these methods make inferences about passenger strategies using Automated Vehicle Location (AVL) and Automated Fare Collection (AFC) data.

Strategy information can also be gleaned more directly by asking passengers about their strategies in a survey. To this end, a web-based survey was developed. Some analysis was devoted to the representativeness and validity of the survey results to determine the viability of web-based surveys to collect data on route choice strategies, as well as to collect other ridership information.

For network and service planning, it is useful to understand not only which strategies passengers are using, but also why they select the strategy they do. Data from the web-based survey, as well as the inferences from the analysis of automatically collected data identify some explanatory factors that are correlated with passengers' route choice strategy.

Knowledge of passengers' route choice strategies and of the reasons behind these choices can help planners make better decisions about network design, service frequency, and the operation of buses in a corridor. This thesis considers the implications of the information gained from studying the two London corridors both for improvements to the specific corridors and as a more general source of information for corridor design and planning.

## 1.1 Motivation

London is an appropriate setting for this research because its bus network is both dense and well-used. London has a ratio of over 900 buses per one million residents (Land Transport

Authority, 2010) and these buses have a high utilization rate of an average of .3 million passengers per bus per year (LTA Academy, 2011). London residents make an average of .6 bus trips per day (Golub, 2004). With such high demand for bus service, London operates a bus network with many overlapping routes. As a result, about 40% of London's bus trips can be made on more than one bus route (Sanchez Martinez, 2013). Understanding passenger behavior in the face of a bus route choice decision can therefore shed light on the experience of millions of London bus passengers.

The dense and heavily-used nature of the London bus network is not unique world-wide. Singapore's bus network shares very similar statistics, with a bus fleet ratio of about 800 buses per one million residents (Land Transport Authority, 2010) and a utilization rate of .29 million passengers per bus per year (LTA Academy, 2011). Seoul counted an average of 5 million bus passengers per day in 2004 (Pucher et al., 2005) or .58 trips per resident per day (Golub, 2004). In Hong Kong, residents make an average of .71 bus trips per day and even higher bus ridership is observed in Brazil, with residents of Rio de Janeiro and Curitibia making an average of 1.00 and 1.02 bus trips per day, respectively. While bus ridership in the United States tends to be lower, New York City is not far behind London with an average of .53 daily bus trips per resident (Golub, 2004). In other parts of the world, a large volume of informal bus service speaks to the potential for planned multi-route bus corridors. Cairo, for example, has an average of 3.5 million passengers per day on the buses operated by the Cairo Transit Authority, and estimates an additional 6.5 million passengers per day on unregulated minibuses (Rodriguez, 2012).

In cities worldwide, concentrated demand for bus service has led to a focus on bus corridors. Guangzhou, China has developed a 22.4 kilometer bus rapid transit (BRT) corridor that is served by 31 different bus routes (Hughes and Zhu, 2011). The most-used bus corridor in Sao Paolo, Brazil serves 200,000 passengers every day. Bogota, Colombia is famous for its Transmilenio BRT system, which inspired similar systems in Jakarta and Mexico City (Golub, 2004). The prevalence of bus corridors worldwide underscores the importance of developing an understanding of these corridors in terms passenger behavior and its implications for service and network planning.

Passengers who board and alight in a multi-route corridor have a choice of more than one bus route to make their trip. The strategies they use to select between these routes can impact important components of the bus passenger experience, including waiting time and vehicle loads. When the routes a passenger can select are of the same service type, researchers often assume that individuals take the first bus that serves their destination. This strategy assumes that the individuals have full knowledge; that is, they are aware of all the buses that serve their destination. It also assumes that buses are not reaching capacity constraints, in which boardings are denied because the bus is too full. One can also think of other scenarios where individuals may not take the first bus. They may choose to wait for a less-crowded bus even though they could have boarded a crowded bus sooner. There is also room for adaptive strategies. They may start off waiting for a less-crowded bus, expecting buses of another route to be less crowded. After a couple crowded buses pass, they may opt to board the third, equally crowded bus because they no longer expect future buses to be less crowded or are simply tired of waiting.

When passengers have options with varied service types, such as the choice between local service and limited stop service, there is additional potential for strategy variation. People who live closest to a bus stop served only by local buses may select to walk to a farther stop that is served by limited stop buses as well. However, this decision may depend on real-time information they access about arrivals at each stop. Once at a combined (local and limited stop) bus stop, individuals may choose to wait for a limited stop bus or may not. This decision may depend on the expected arrival times for each route. People who do not have access to information may vary their behavior based on previous experiences or may plan to wait for a limited stop bus and then give up on it after a certain number of minutes. Passengers' route choice strategies may also depend on characteristics of the routes, such as levels of crowding, characteristics of the trip, such as its length and purpose, and characteristics of the individual, such as his or her level of risk aversion and sensitivity to waiting time.

Route choice strategies are latent, or unobservable, making it necessary to develop methods to infer strategies based on observable data, such as vehicle location and passenger boarding data, or to find ways to reliably identify strategies through a survey. This thesis attempts to do both, as the analysis and evaluation of passengers' route choice strategies is critical to any study of multi-route corridors. Depending on a passenger's strategy, his or her waiting time and in-vehicle time may be a function of the headways and running times of just one route or of multiple routes. For passengers who take the first bus that serves their destination, average waiting time and in-vehicle time will be a function of the headways and running times of all possible routes. For those who prefer a specific route, these metrics should be judged based on the values for that route only. An understanding of route choice strategies can be incorporated into demand assignment to different routes in a corridor. Strategies will interact with the levels of service on the routes and this in turn will affect the load on vehicles of each route.

This implies that knowledge of passenger route choice strategies is important at each stage of bus network and service planning and operation. First, when evaluating existing service on a corridor, planners should understand that metrics such as expected waiting and in-vehicle time will vary depending on the passengers' route choice strategy. Similarly, these strategies should be considered when evaluating potential service and network changes, such as altering the allocation of vehicles to routes on the corridor or changing stop locations. Passengers may alter their strategies in reaction to these service and network changes, which is why understanding the factors that influence route choice strategy is also important. Planners can use knowledge of the explanatory factors that affect route choice strategy to predict passengers' responses to changes and then evaluate the options given the predicted distribution of route choice strategy. An understanding of route choice strategies on existing corridors can also inform planners when designing new corridors or considering the addition of a new service, such as a limited stop bus route, to a corridor. Route choice strategy is important for schedule planning and route operation, as well, as passengers who are willing to board multiple routes could potentially benefit from bus scheduling and operation that is coordinated at a corridor level, rather than at an individual route level.

## 1.2 Objectives

This research will analyze bus users' route choice in two types of multi-route corridors. In the first all bus routes run the same service pattern, stopping at all stops along the common segment. The second type of corridor has both limited stop and local service.

The first goal of the research is to develop a methodology to characterize the strategies used by bus passengers traveling in the corridor. This is done by making inferences from AVL and AFC data, as well as using a web-based survey. This thesis also evaluates the viability of using an internet survey to collect information about route choice strategy and other bus trip and passenger information. The second goal of the research is to assess the factors that influence passengers' strategy choice. This analysis uses both the inferences made from the AVL and AFC data and the data collected in the survey. Finally, this research considers the implications of these findings for network and service planning and corridor operation.

## 1.3 Overview of Methodology

In this thesis, passenger behavior in a multi-route corridor is characterized by the passengers' route choice strategies. While a variety of adaptive and flexible strategies may exist, this thesis simplifies the characterization by defining passengers as having either a first bus strategy or a favorite bus strategy. Passengers with a first bus strategy take the first bus that serves their destination. Passengers with a favorite bus strategy wait for a bus of a specific route and take that route only. In corridors with limited stop service, passenger strategy also includes the decision of which stop to board at, as the limited stop service route does not serve all stops. While this is an important part of passenger strategy on corridors with limited stop service, the majority of the analysis in this thesis focuses on the route choice strategy decision made after the stop has been selected.

First, three methods are developed to characterize passenger behavior using AVL and AFC data. The first is an empirical analysis that compares the expected proportion of passengers on each route, under the assumption that passengers board the first bus that serves their destination, to the actual proportions of users on each route. The second method is a probabilistic model that infers passengers' route choice strategies from the headways that precede each boarding. The final method is a panel analysis that considers the variation in behavior of individuals who have multiple trips on the corridor over time.

Each of these methods are applied to two corridors in London. The first is called the Beulah Corridor and consists of two local bus routes that run parallel in the Beulah Hill area, south of Central London. The second is referred to as the Uxbridge Corridor and includes a limited stop bus route that parallels two local service routes from White City Bus Station to Uxbridge, west of Central London.

In addition to the inferences made from the AVL and AFC data, information on route choice strategy was collected from a web-based survey of users of the Uxbridge Corridor. Using both the inferences and the survey data, correlations are drawn between route choice strategies and explanatory factors, including trip length, crowding, experience, information, passenger attitudes, age, disabilities, gender, income, trip purpose, and time of day.

Finally, the strategy analysis is combined with ridership data to make recommendations about service and network planning and to quantify the potential affects of operational changes such as the introduction of headway coordination at a corridor level.

## 1.4 Outline of the Thesis

The remainder of the thesis is organized as follows:

Chapter Two provides additional background for this thesis by reviewing the existing literature on strategy identification and understanding route choice strategy. It also includes a brief synopsis of other work that has been done on bus corridor design and planning, focusing particularly on research that has attempted to incorporate route choice strategy in service and network planning decisions.

Chapter Three introduces the two corridors that were studied. Background information and statistics for each corridor are discussed.

Chapter Four focuses on three methods to infer route choice strategy using AVL and AFC data. Detailed methodologies as well as the results for the Beulah and Uxbridge corridors are presented. In addition, the data is segmented to evaluate the affects of trip length, crowding, experience, and information on route choice strategies in these corridors.

The web-based survey is presented in Chapter Five. This chapter explains the contents and design of the survey and also presents an evaluation of the representativeness and validity of the survey data.

Chapter Six uses the data collected in the web-based survey to assess the contributions of trip length, crowding, experience, information, passenger attitudes, age, disabilities, gender, income, trip purpose, and time of day to passengers' route choice strategies.

In Chapter Seven, the implications of the results for network and service planning and operations are discussed.

Chapter Eight states the main conclusions of this research.

# Chapter 2

# Literature Review

This chapter begins with some of the major recommendations and findings for service and network planning in high-demand corridors, which are often served by multiple bus routes. Next, a summary is provided of the research that has contributed to an understanding of user strategies in a transportation context. Finally, these two topics are brought together in a discussion of studies that propose methods for incorporating user strategies into demand assignment models used to make service and network planning decisions. This thesis develops new methods for understanding route choice strategies in multi-route bus corridors and uses this understanding to make recommendations for network and service planning and operation in multi-route corridors.

## 2.1 Service Planning for Multi-Route Corridors

When demand on a corridor is sufficient to justify multiple bus routes, the passenger experience can be improved by diversifying service to suit the varied trips made on the corridor. Furth and Day (1985) summarize four service configuration options for heavy demand corridors: short-turning, restricted zonal, semi-restricted zonal and limited-stop zonal. Limited stop service, the option used in the Uxbridge Corridor, is defined as having a typical stop spacing of .5 to 1 miles. Furth and Day (1985) discuss the operational needs of each option such as the reliance on overtaking and the need for schedule coordination. For limited stop service, they indicate a strong need for overtaking and potential value in schedule coordination, particularly during peak travel periods. They also note that limited stop service is ideal for long corridors with fast ambient travel speeds.

Larrain et al. (2010) build on this research, focusing on defining the characteristics that make a corridor ideal for express service[1]. They consider four parameters: the shape of the load profile along the corridor, the scale of demand, the demand imbalance between outbound and inbound travel, and the average trip length. They evaluate the potential benefits to passengers of express service under different values for the four parameters using simulation. They find that the most important parameter is average trip length, with more potential benefits of express service as the length of the average passenger trip increases.

[1]In many United States transit agencies, limited stop service is called “express”. For the purpose of this research the two terms are used interchangeably.

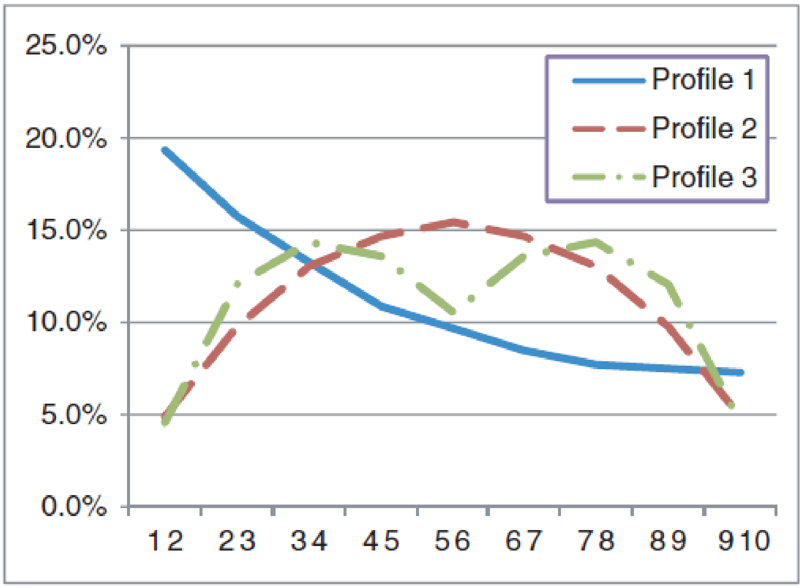



**Figure 2-1:** Load Profiles (from Larrain et al. (2010))

The shape of the load profile also influences potential benefits. The benefits are greatest for base load profiles that decrease monotonically, though peaked profiles also showed some benefit. Where load profiles have multiple peaks, more complex service patterns may be appropriate. Figure 2-1 shows a monotonically decreasing load profile (Profile 1), a peaked load profile (Profile 2) and a load profile with multiple peaks (Profile 3). The researchers also found a correlation between higher demand levels and potential benefits, though the relationship is weaker than expected. Finally, they do not find any meaningful relationship between the demand imbalance between inbound and outbound travel and the potential benefits of limited stop service.

This thesis analyzes other characteristics of the route, trip, and corridor, that are correlated with a strategy of waiting specifically for a limited stop service route. This helps identify additional factors that make a corridor a strong candidate for limited stop service. While not the main focus of this thesis, some consideration is given to stop choices and some recommendations with regard to stop locations is also given.

Chiraphadhanakul and Barnhart (2012) look in detail at stop configurations. Their service optimization model re-allocates buses from a local route to a parallel limited-stop route. The network based model determines which stops the limited stop route should serve as well as the number of vehicles that should be shifted from local to limited stop service. The model maximizes total welfare which is defined as the travel time savings minus the additional waiting time.

In terms of scheduling and operation, Ceder et al. (2001) discuss an algorithm developed to maximize the number of simultaneous bus arrivals at transfer nodes in the bus network. Verma and Dhingra (2006) propose a method for optimizing coordination between bus feeder routes and urban rail systems. Delgado et al. (2009) evaluate how two operational strategies, vehicle holding and boarding limits, can reduce the time passengers spend waiting and traveling in a bus corridor. This thesis builds on this work by using strategy analysis to demonstrate the potential benefits of schedule planning and operation at a corridor (instead of single route) level.

## 2.2 Understanding User Strategies

In transportation, a strategy can be defined as a choice set and a decision rule. Kurauchi et al. (2012) conducted an exploratory survey in an attempt to understand passenger strategies in multi-route corridors. They found that passengers tend to consider a set of possible routes rather than one fixed path. The passengers surveyed were flexible both in terms of route choice and stop choice. Those who did not have accumulated knowledge from repeated trips on the corridor relied on information provided and were less flexible in their path choice than passengers who relied on their own knowledge and experiences.

Choudhury et al. (2010) also studied strategies, applying a dynamic latent plan model to driver strategies for entering a freeway. The dynamic latent plan model attempts to address the evolutionary nature of strategies that Choudhury et al. (2010) identify. They specify four factors that cause plans to evolve. First, people may be influenced by contextual changes. In the bus route choice context, this could include buses that are more crowded than expected. Second, people are influenced by past experiences. If they have to wait a long time for limited stop one day, they may choose not to wait for it the next day. Third, people have inertia in their plan choice. They may continue to go to their closest local stop, because it is a route they know well, whereas they would have to plan a new walking route to go to a stop served by a limited stop bus. Finally, people may change plans due to time-inconsistent preferences. For example, people may alter their behavior when they realize they are running late.

This thesis does not focus on the dynamic aspect of plan formation, but rather attempts to expand the understanding of passenger strategies in multi-route corridors by developing methods to identify passengers' route choice strategies and the factors that explain these choices. One important contribution is the development of a web-based survey to collect information on passenger strategies, details of their trips, and personal characteristics. Not only does this demonstrate the feasibility of using a web-based survey for data collection, but it allows for a deeper understanding of passenger behavior in multi-route corridors.

## 2.3 Incorporating Strategy Analysis in Service Planning

Passengers' access and egress time, waiting time, and in-vehicle time on a multi-route corridor depend on the strategy that they use to select a boarding stop and route. Strategies influence the demand for each route as well as the loads on vehicles in the corridor. Passengers are likely to change their strategies in response to service changes on a corridor. It is complicated to incorporate this interactive relationship between route choice strategies, demand, and quality of service into decisions about service planning. While some models for service planning on multi-route corridors make strong simplifying assumptions about passenger strategies, others have attempted to incorporate the concept of a route choice strategy.

Lampkin and Saalmans (1967) describe a method to determine the service frequencies on a multi-route corridor that minimizes the sum of total travel time for all passengers. Their method assumes fixed demand by origin and destination (OD) pair and allocates it deterministically to the route with the shortest total travel time. This does not incorporate the concept of choice set of routes that Kurauchi et al. (2012) discusses. This is problematic, as the following example demonstrates. A passenger's preferred boarding and alighting stop are served by two bus routes. Both routes have the same in-vehicle time between stops, but Route 1 has headways of ten minutes and Route 2 has headways of two minutes. The expected waiting time for Route 1 is therefore longer than the expected waiting time for Route 2. Using deterministic assignment to the route with the shortest travel time, all flow would be assigned to Route 2. In reality, passengers are likely to board whichever of the two routes arrives at their stop first.

Han and Wilson (1982) introduced some complexity to the demand assignment process by defining passengers as part of either captive flows or variable flows. Passengers who can only take one route to their destinations make captive flow trips while passengers with options make variable flow trips. The variable flow trips are divided between the possible routes according to their frequency shares. While this does not incorporate any sort of decision rule that passengers use to select between routes, it does account for passengers' tendency to consider a set of route options rather than a single route for their trips. Han and Wilson used this method of demand assignment in a model that allocates a fixed number of buses to parallel routes, in a manner that avoids vehicle capacity issues. The model estimates the number of vehicles that should be assigned to each route to minimize passenger flow[2] on each route subject to loading feasibility and fleet size constraints. The loading feasibility constraint guarantees that on average, there will be capacity on each vehicle for the waiting passengers to board.

Chriqui and Robillard (1975) also used the idea that passengers conceive of a set of routes that serve their destination and board whichever arrives first. They assert that passengers may not be willing to take all possible routes, if some take much longer than others. Instead, they formulated an optimization problem that generates a set of optimal routes that passengers traveling between a given OD pair would be willing to take. Their model also accounts for variation in vehicle arrival processes of different routes by allowing the planner to input different arrival distributions for each route. The model assumes that passengers board the first vehicle to arrive out of the optimal route set. They argue that this model provides more realistic estimates of loads on parallel links within a bus network. Spiess and Florian (1989) used a similar method to model passenger decisions at each transfer point in a network. Again, this provides public transit planners with more accurate demand assignments, and Spiess and Florian also suggest that it may be useful for other transportation applications such as the shipment of freight by different modes.

Focusing on a multi-route bus corridor in Chicago, Schwarcz (2005) developed a model tailored for corridors that have both local and limited stop service, in which not all passengers board the first bus to arrive that serves their destination. The model takes the existing demand for specific origin and destination pairs along the route and re-assigns it to one of three different markets using an all-or-nothing allocation minimizing total weighted travel time. The three markets are local preferred (those people who board at a stop served only

[2]Due to the difficulties of specifying a function of passenger flow, the model uses the occupancy at the peak stop as a proxy.

by local buses or choose to wait for local service), limited preferred (people who go to a stop that is served by the limited stop route and wait for limited stop service) and choice passengers, who she defines as people who will go to a stop that is served by local and limited stop service and will take the first bus to arrive. Based on these market shares, her model reassigns demand at the stop and route level. An important component of her model is the estimation and use of weights for each type of travel time. Passengers typically perceive access, waiting, and in-vehicle time differently. Schwarcz estimated these weights by applying five different sets of weights to her model for Chicago's Western Avenue and determining which set most closely replicated reality. She then used her strategy assignment model to evaluate different potential service frequencies for limited stop and local service on the corridor.

In evaluating these service changes, Schwarcz assumes that demand on the corridor is fixed. Scorcia (2010) created a variable demand model that uses elasticities to predict demand changes in response to changes in travel time. He used an existing corridor in Chicago that had recently implemented limited stop service to estimate elasticities of demand. Like Schwarcz, Scorcia divided the population into three markets: local preferred, limited preferred, and choice. While Schwarcz assigned demand to the strategy with the minimum travel time, using all-or-nothing assignment, Scorcia used strategies identified in an onboard survey to estimate a logit model that explained strategy choice in terms of weighted components of travel time. In the onboard survey, he asked passengers to identify their strategy - whether they waited for local or limited stop service or took the first bus.

By conducting this survey, the work by Scorcia represents a departure from the previous studies, which made assumptions about strategies rather than attempting to measure them directly. This thesis builds on this work by providing three methodologies to infer route choice strategies from AVL and AFC data, and also by conducting a web-based survey on route choice strategy and related factors. The web-based survey data includes information on many additional factors that Scorcia could not ask about in his shorter onboard survey. For example, the survey conducted here collects information on attitudes such as sensitivity to crowding and levels of risk aversion. These questions were based on a survey conducted by Carrier (2008) who found that attitude influenced individuals' selection of airline itineraries.

In addition, Scorcia was only able to survey 182 people, while the web-based survey was answered by more than 9000 individuals, and the methods for inferring strategies from AVL and AFC data can be applied even more broadly. Both the survey data and the inferences from the AVL and AFC data can be used to test the assumptions about route choice strategies that are used in demand assignment models. The analysis of the explanatory factors that are linked to route choice strategy can also inform these models and improve planners' evaluations and decision-making processes with regard to multi-route corridors. This thesis strengthens the connection between a more detailed assessment of passenger route choice strategies and network and service planning, such as decisions about stop locations and the allocation of vehicles to routes. It also uses the strategy assessment to quantify some of the benefits of corridor-level schedule planning and operation.

# Chapter 3

# Background Information on the Case Studies

In this thesis, route choice strategy identification techniques are applied to two corridors in London. The first is a corridor in the Beulah Hill area of South London (the Beulah Corridor), which consists of two parallel local service routes. The second corridor runs east-west from White City Bus Station to Uxbridge (the Uxbridge Corridor) and is made up of a limited stop service bus route that overlaps with two local service routes. This chapter summarizes background information about each of these corridors and also specifies the data sources used for analysis.

## 3.1 Beulah Corridor

In the Beulah Corridor, Route 196 and Route 468 run parallel for approximately 6.2 km (3.9 miles). Figure 3-1 shows a map of the corridor. They share 23 stops in the inbound direction and 26 stops in the outbound direction. Table 3.1 summarizes the corridor ridership and headways. The average weekday ridership is determined from ten weekdays in September and October 2012. Passengers whose Oyster card (smartcard) transactions revealed that they both boarded and alighted in the corridor (at stops served by both routes) were counted, and these numbers were scaled up at a route level to reflect Electronic Ticket Machine (ETM) counts for the ten days. Over 6,000 passengers board and alight in the Beulah Corridor each weekday. Route 468 provides more frequent service with headways of seven minutes in the inbound morning (AM) peak and headways of six minutes in the outbound AM peak. Route 196 has somewhat longer AM peak headways of eleven minutes.

**Table 3.1:** Beulah Corridor Ridership and Headways

| | Average Weekday Ridership | | AM Peak Headway | |
|---|---|---|---|---|
| | Inbound | Outbound | Inbound | Outbound |
| Route 196 | 1,138 | 1,239 | 11 | 11 |
| Route 468 | 1,868 | 2,119 | 7 | 6 |

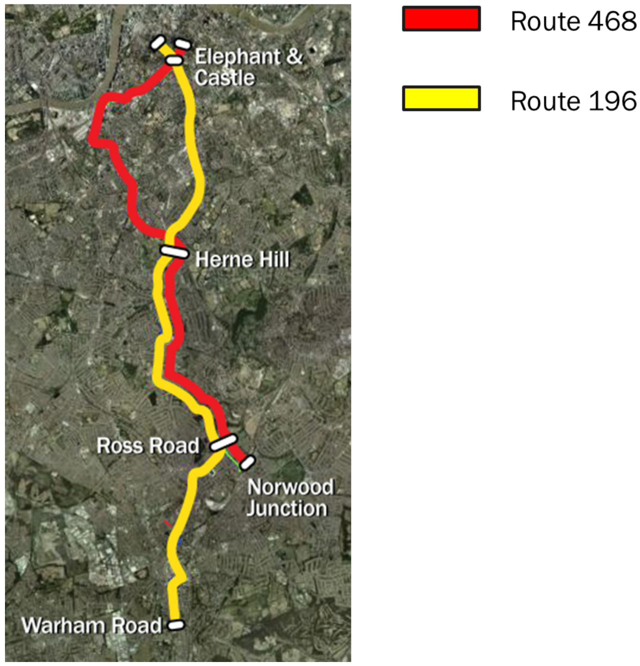



**Figure 3-1:** Map of the Beulah Corridor

Figure 3-2 shows the frequency with which passengers use the corridor over the ten weekdays analyzed in September and October. The majority of passengers who used the corridor in these ten days took just one trip on the corridor. Figure 3-3 displays the same data in another way, showing the proportion of trips made by different user types, categorized as infrequent, semi-frequent, frequent, or very frequent users. Less than 30% of trips are made by infrequent users, passengers who made just one or two trips on the corridor in the ten-day period. However, the majority of trips (almost 70%) in the corridor are made by infrequent or semi-frequent users, who made eight trips (or four round trips) or fewer over the ten-day period. Only 32% of trips on the corridor were made by frequent or very frequent users.

The majority of the analysis in this thesis focuses on the AM peak period, which was defined by considering a histogram of boardings on the corridor by half hour period. Figures 3-4 and 3-5 show the boardings by time of day on the corridor during the ten weekdays analyzed. In both directions, the AM peak shows a clearly defined rise in the number of boardings. In the inbound direction, the AM peak was defined as lasting from 7:00 to 9:30, while in the outbound direction, the AM peak is slightly shorter, lasting from 7:30 to 9:30.

These definitions were used to determine the median and range of loads on the two routes in the corridor. Each vehicle trip on a route is numbered and the AFC data records the vehicle trip number for the bus that an individual boarded. Using this boarding information and the inferred alighting stop for each passenger (alighting stops were inferred by the ODX program, see Section 3.3), the loads for each vehicle trip at each stop can be calculated. Because these loads only include passengers with inferred origin and destination stops, these values are scaled up by a constant at the route level to reflect ETM counts. All vehicle trips that reached the first stop in the corridor during the hours defined as the AM peak were used to calculate median, tenth percentile and ninetieth percentile loads. Figures 3-6

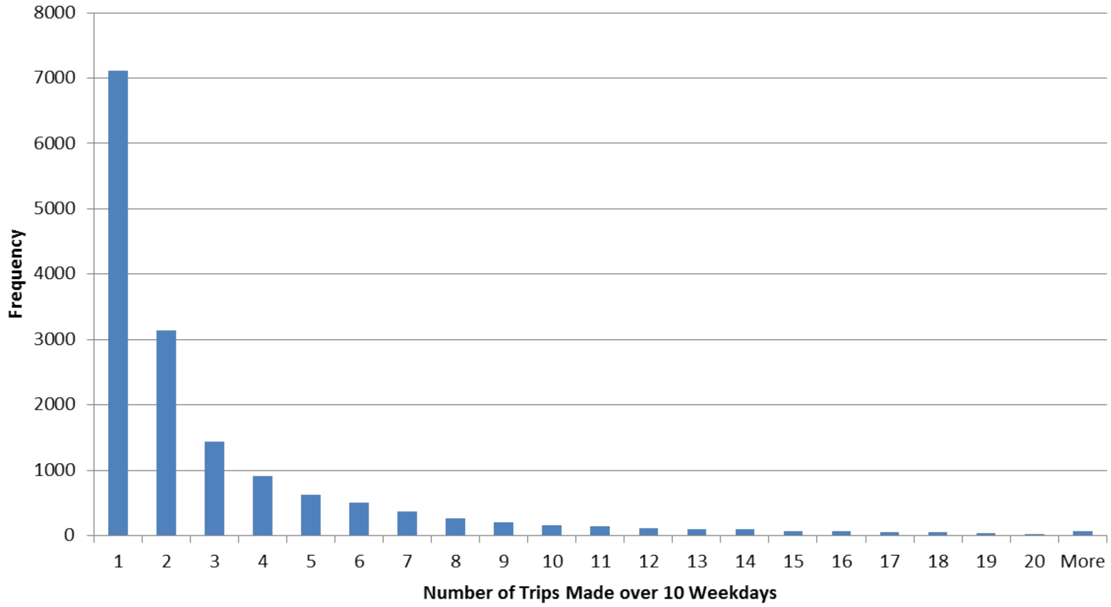



**Figure 3-2:** Frequency of Beulah Corridor Use

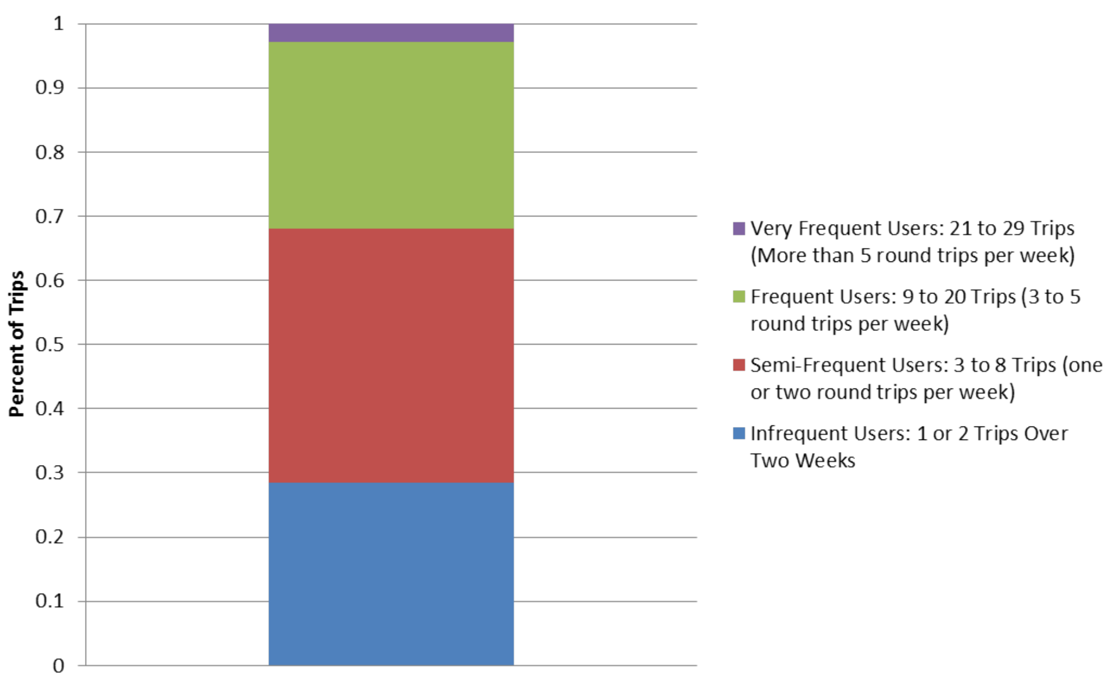



**Figure 3-3:** Beulah Corridor Trips by User Type

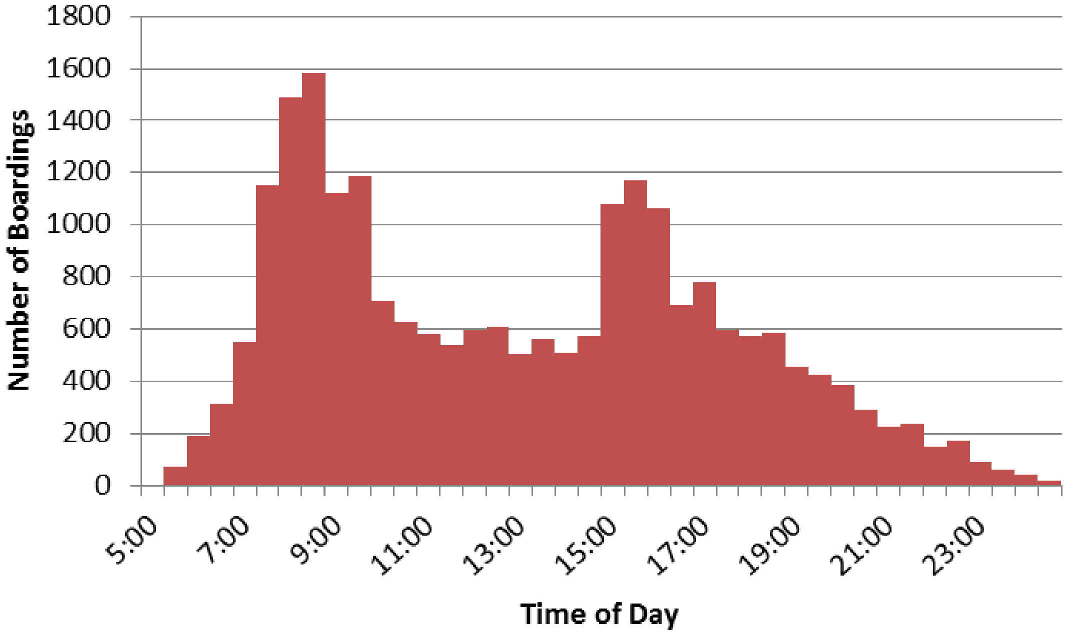



**Figure 3-4:** Beulah Inbound Boardings by Time of Day

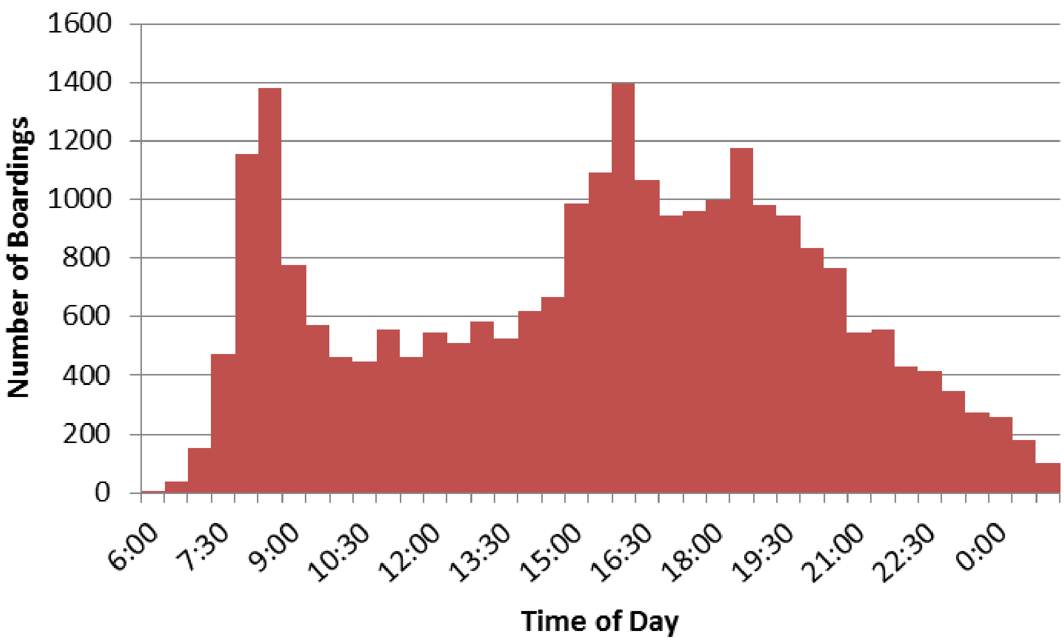



**Figure 3-5:** Beulah Outbound Boardings by Time of Day

and 4-5 show these values for the stops on the corridor using the data from ten weekdays in September and October 2012. Loads in the inbound direction are higher than in the outbound direction, and there is not much variation in load in either direction. The loads on Route 468 buses are somewhat higher than the loads on the Route 196 buses.

Three stops in the inbound direction and one stop in the outbound direction are geographically offset for the two routes. That is, the stop for the Route 196 buses is a block or more away from the stop for the Route 468 buses. An example is shown in figure 3-8 of the Norwood Road/ Robson Road stops. These slight geographic discrepancies could cause bus users to favor one route or another if they are boarding or alighting at one of these stops. In addition, passengers who board at these offset stops are forced to choose to wait at one stop or the other, meaning that they must select a stop to board at rather than a route to board. Therefore, all trips that included a boarding or alighting at one of these stops were removed from the majority of the analysis, and set aside for a special panel analysis of passengers' flexibility of stop choice which is summarized in Chapter 4.

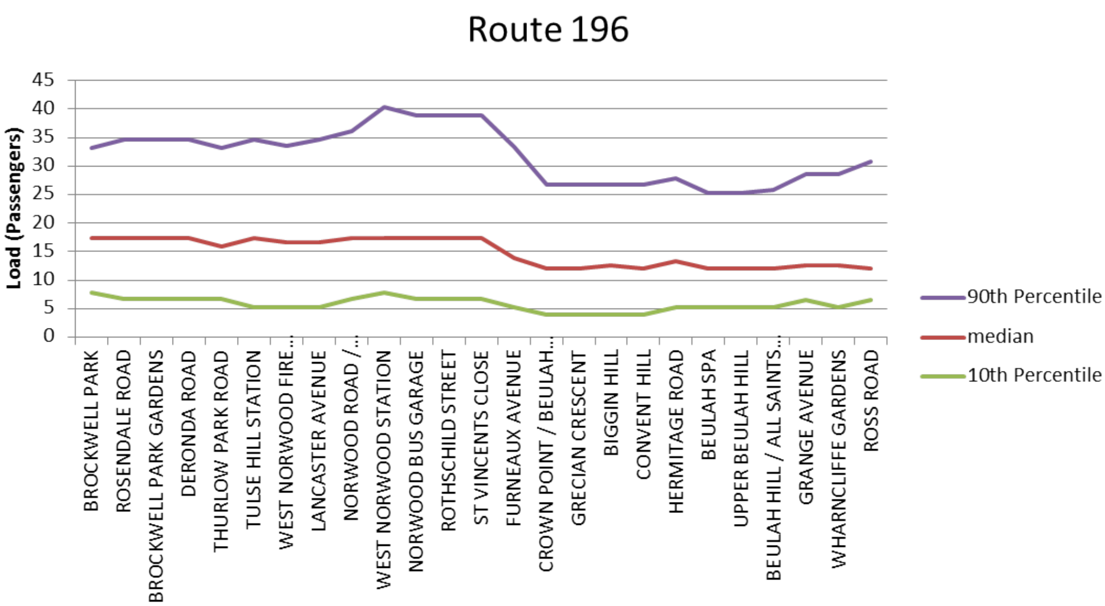
Several other routes run parallel to routes 196 and 468 for parts of the corridor. Routes x68, 249, and 690 each visit eleven or more stops along the corridor. The strategy identification analyses presented in this thesis are dependent on the number of routes an individual can choose from and on the specific characteristics of each of these routes. Therefore, the analysis focuses exclusively on passengers traveling between OD pairs served by routes 196 and 468 only. Table 3.2 shows how this restricts the number of OD pairs and the number of trips covered in this analysis. Because of the prevalence of parallel routes in this area, only 25% of inbound trips and 35% of outbound trips are considered in the analysis presented in Chapter 4. However, to gain insight into the behavior of the other users of the corridor, the analysis could be repeated for the ODs served by each set of parallel routes.

**Table 3.2:** Summary of Beulah Corridor Data for Analysis

| | OD Pairs Included | Oyster Trips Over Ten Days | % of Corridor Ridership |
|---|---|---|---|
| Inbound | 90 | 7,380 | 25% |
| Outbound | 137 | 11,912 | 35% |

## 3.2 Uxbridge Corridor

The Uxbridge Corridor is about 20.2 km (12.6 miles) long and is served by three routes: 207, 427, and 607. Route 607 is a limited stop route, which skips up to five consecutive local stops. Traveling inbound from Uxbridge, Route 607's first six stops (3.9 miles) are also served by Route 427; its next nine stops (5.2 miles) are served by both Route 427 and Route 207; and its final six stops (2.3 miles) are served by Route 207. Figure 3-9 shows a map of this corridor and Table 3.3 summarizes some key corridor statistics. Notably, the corridor serves a high volume of passengers, with more than 90,000 passengers trips daily. The limited stop route, Route 607, has the least frequent service, with headways of eight minutes in the inbound direction and ten minutes outbound. The riderships counts



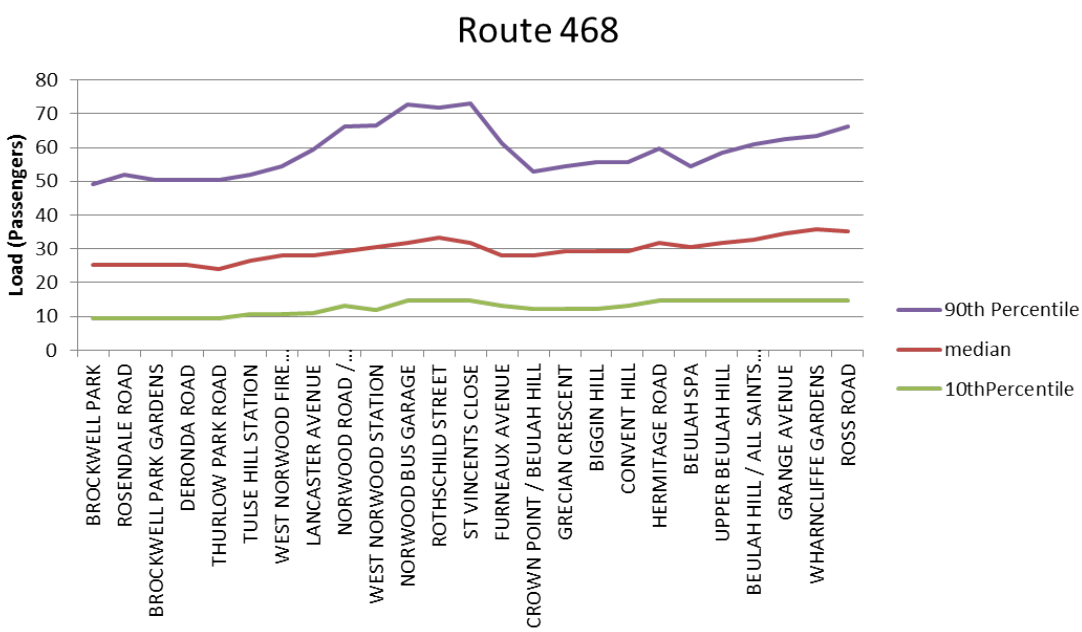
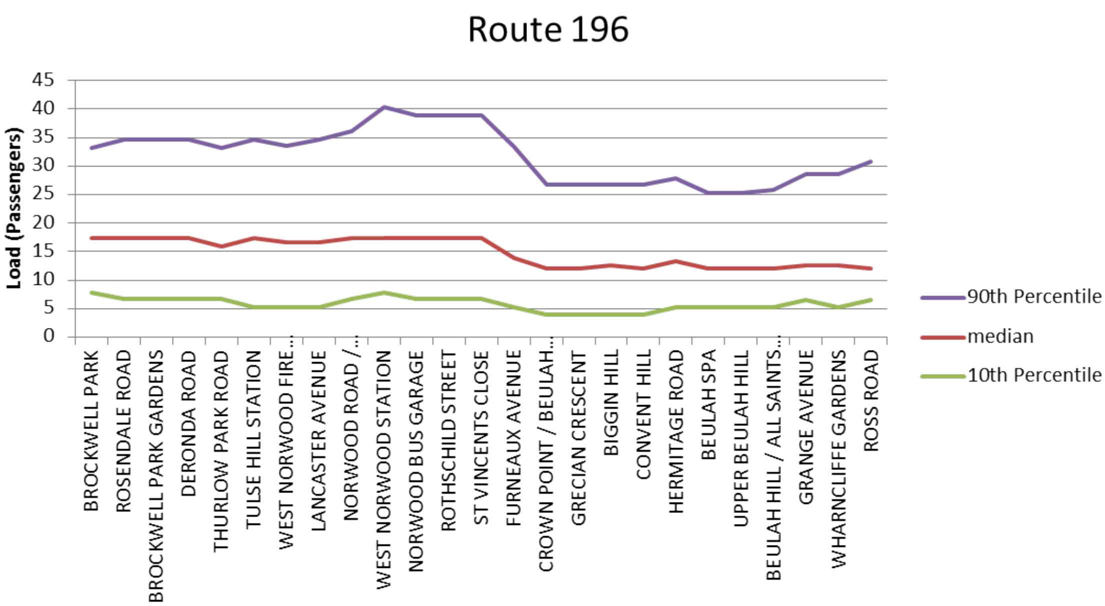




**Figure 3-6:** Beulah Inbound AM Peak Loads



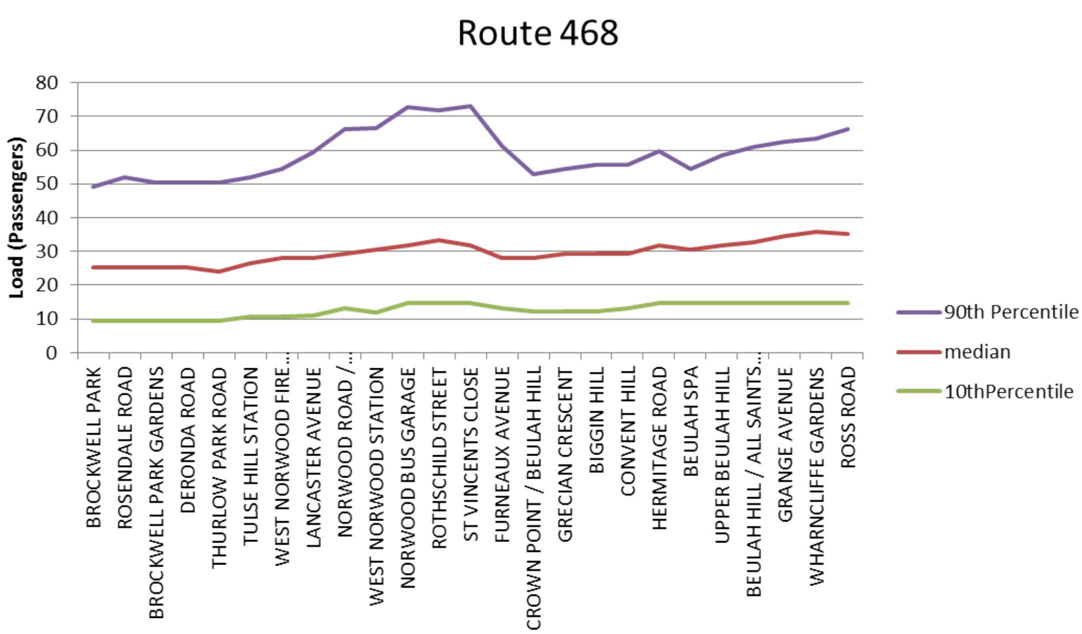




**Figure 3-7:** Beulah Outbound AM Peak Loads

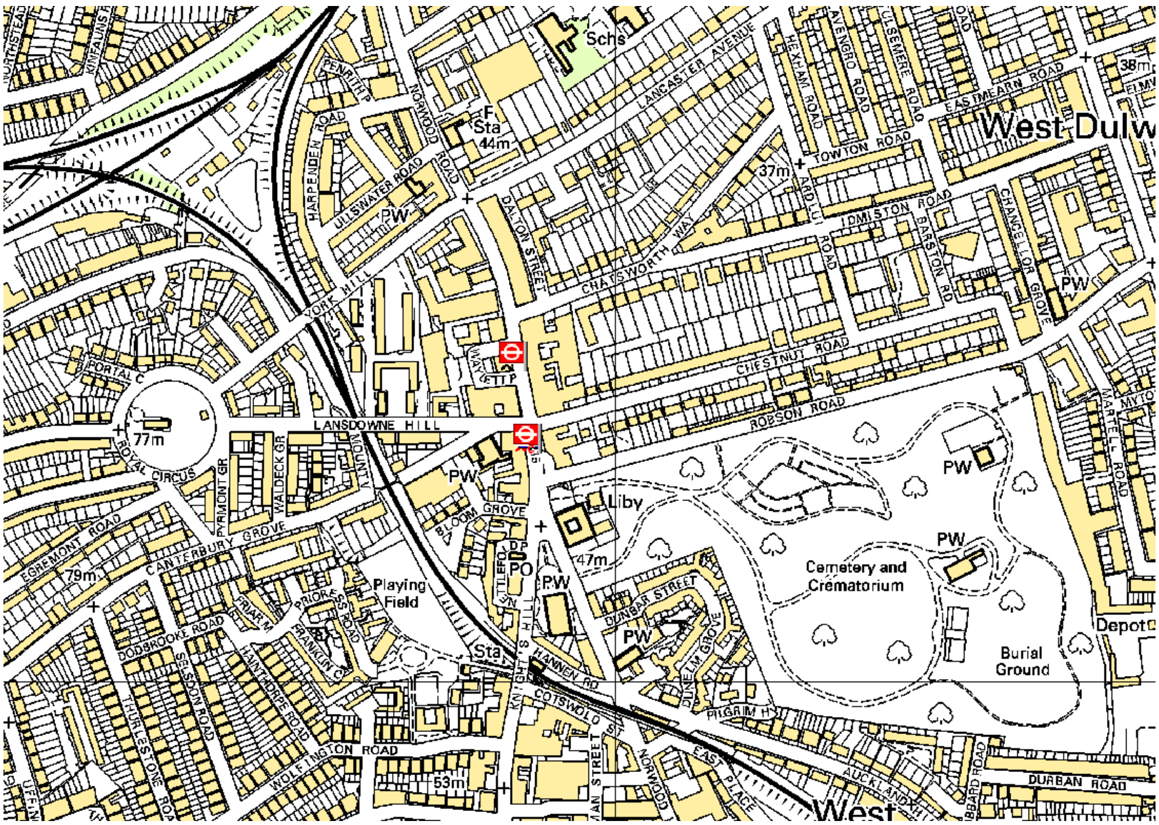



**Figure 3-8:** Map of Offset Norwood Road/ Robson Road Stops

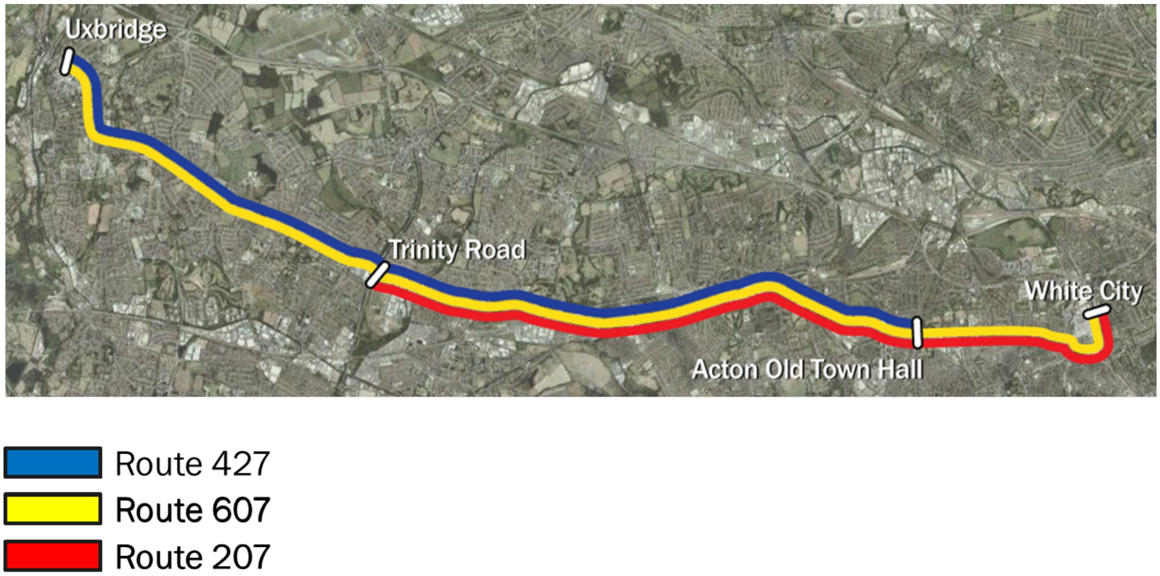



**Figure 3-9:** Map of the Uxbridge Corridor

are from ETM data for ten weekdays in September and October, while the headways are scheduled.

**Table 3.3:** Uxbridge Corridor Ridership, Headways, and Stop Spacing

| | Average Weekday Ridership | | AM Peak Headway | | Average Stop Spacing (meters) |
|---|---|---|---|---|---|
| | Inbound | Outbound | Inbound | Outbound | |
| Route 207 | 21910 | 20754 | 5 | 5 | 306 |
| Route 427 | 12895 | 12507 | 8 | 8 | 312 |
| Route 607 | 12451 | 12042 | 8 | 10 | 1011 |

Figures 3-10 and 3-11 show that shorter trips are served mainly by the local service routes, while longer trips are concentrated on the limited stop service route. Table 3.4 further summarizes the characteristic trip lengths on each route. Typical trips on Route 427 are slightly longer than trips on Route 207 and trips on Route 607 are more than twice the length, on average, of Route 207 trips. The trip lengths are based on Oyster card data processed by the ODX program (see Section 3.3).

Figure 3-12 displays the number of trips made by users in the ten consecutive weekdays in September and October that were analyzed. The majority of passengers on the corridor take one or two trips. Compared to the Beulah Corridor, however, many more of the trips are made by frequent of very frequent users. Figure 3-13 shows that more than half of the trips on the Uxbridge Corridor are made by passengers who make nine or more trips in the ten-day period. This means that while the Uxbridge Corridor has many users, including a large share of infrequent users, the majority of trips on the corridor are made by frequent users.

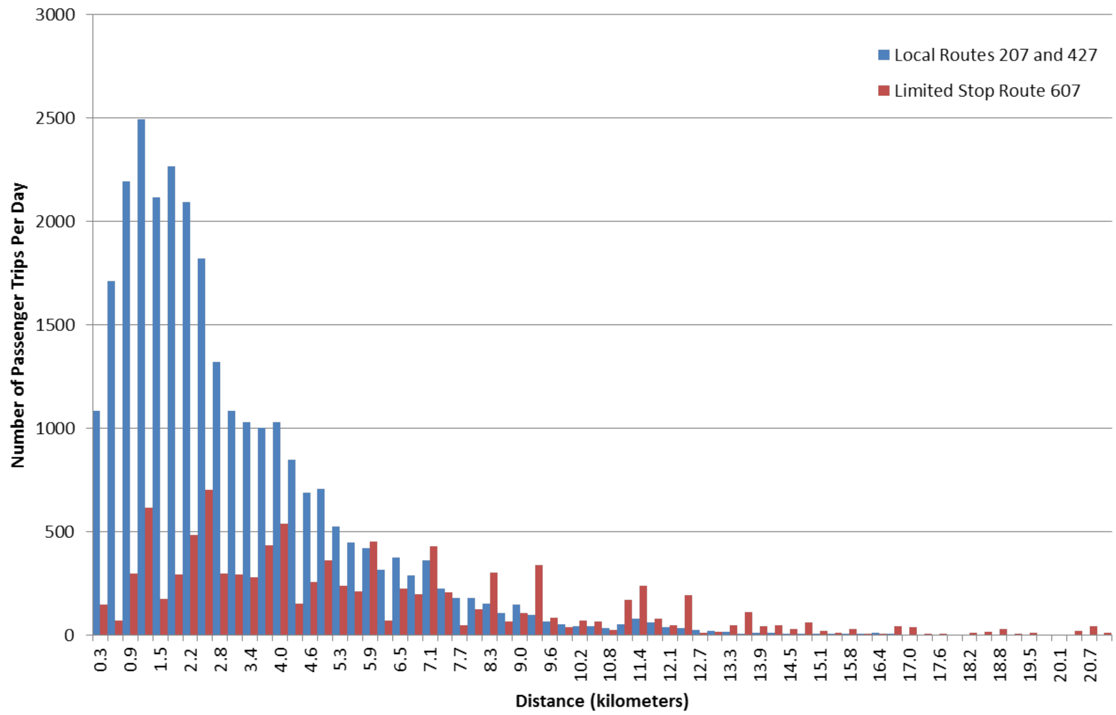



**Figure 3-10:** Inbound Trip Lengths By Service Type

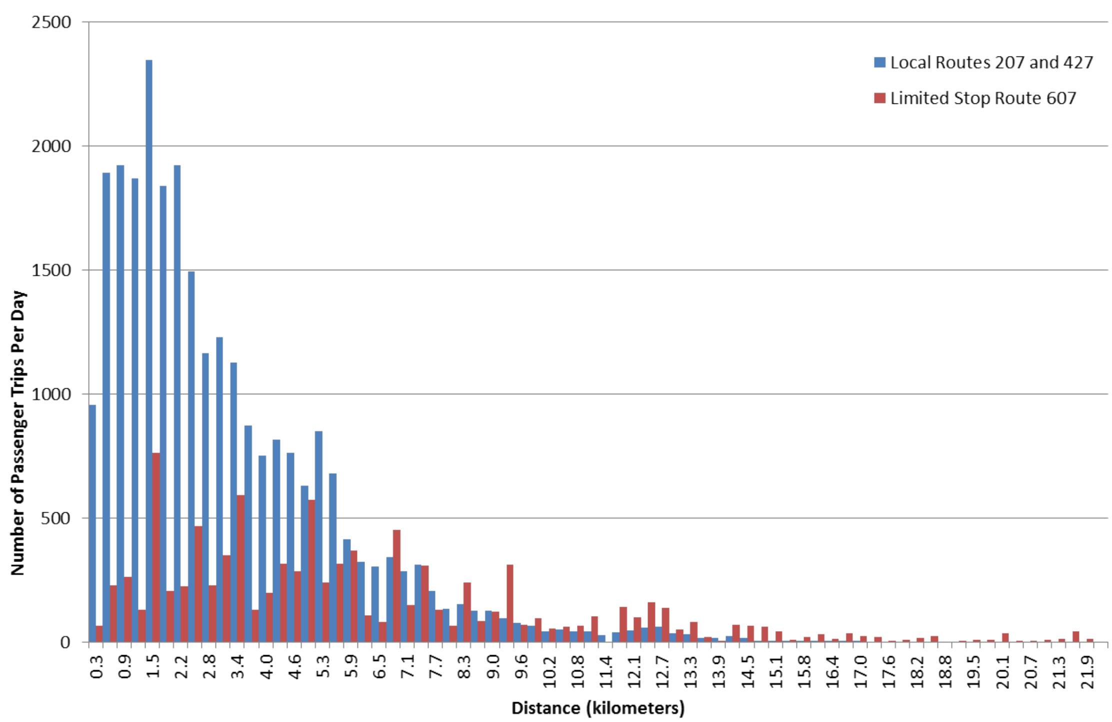



**Figure 3-11:** Outbound Trip Lengths By Service Type

**Table 3.4:** Uxbridge Corridor Trip Lengths by Route (Fall 2012)

| | Inbound | | | Outbound | | |
|---|---|---|---|---|---|---|
| | Mean | Median | Standard Deviation | Mean | Median | Standard Deviation |
| Route 207 | 2.8 km (1.7 mi) | 2.2 km (1.4 mi) | 2.2 km (1.4 mi) | 3.1 km (1.9 mi) | 2.5 km (1.6 mi) | 2.4 km (1.5 mi) |
| Route 427 | 3.3 km (2.1 mi) | 2.5 km (1.6 mi) | 2.6 km (1.6 mi) | 3.3 km (2.1 mi) | 2.5 km (1.6 mi) | 2.5 km (1.6 mi) |
| Route 607 | 5.7 km (3.5 mi) | 4.6 km (2.9 mi) | 4.1 km (2.5 mi) | 6.0 km (3.7 mi) | 4.9 km (3.0 mi) | 4.3 km (2.7 mi) |

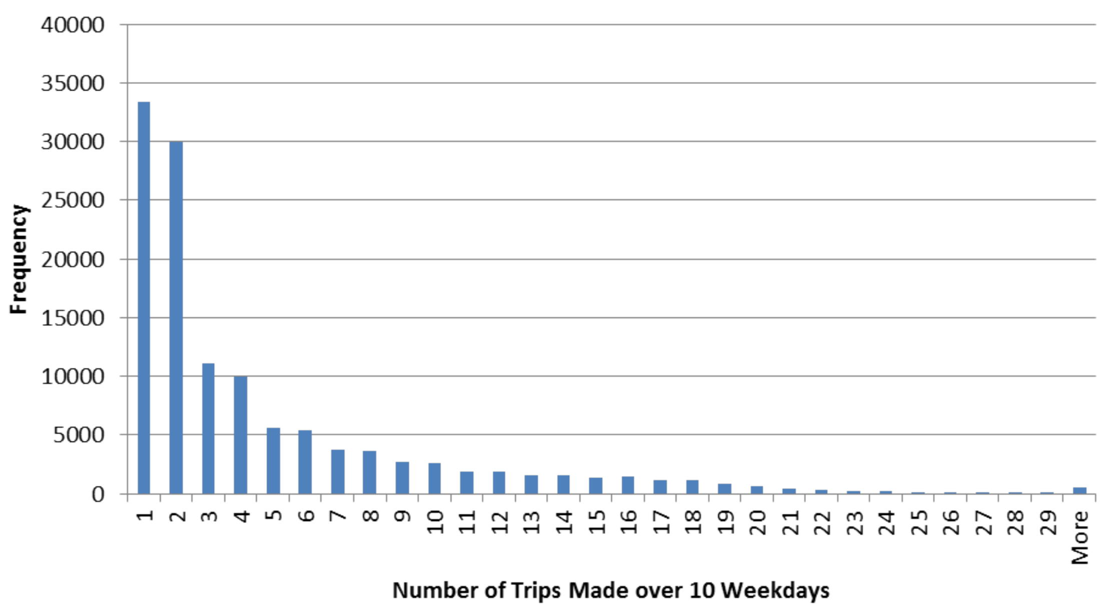



**Figure 3-12:** Frequency of Uxbridge Corridor Use (Fall 2012)

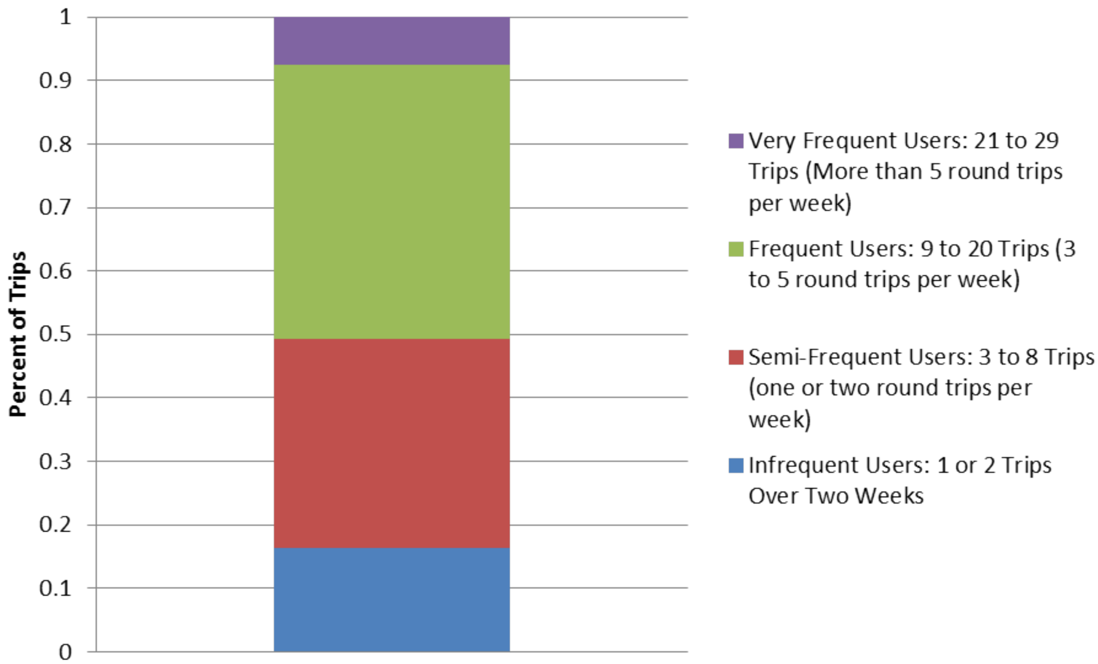



**Figure 3-13:** Uxbridge Corridor Trips by User Type

Due to the configuration of the routes, it is possible that a passenger would transfer from one corridor route to another. For example, a passenger who lives near a local stop on Route 427, may take Route 427 for a few stops until the bus reaches a combined, local and limited stop service bus stop. Then, the user could transfer from Route 427 to Route 607 at the combined stop and continue his or her journey on Route 607 to his or her destination. However, this behavior was found to be very rare. Only 3.3% of trips in the inbound direction and 3.8% of trips in the outbound direction formed part of this type of transfer.

The boardings on the Uxbridge Corridor throughout the day show that while defined AM and PM peaks exist, there is also a high level of ridership in the mid-day period (See figures 3-14 and 3-15. The inbound AM peak, which was the principal focus of analysis, was judged to last from 7:00 to 9:30. Some analysis also focuses on the outbound AM peak which lasts from 7:30 to 9:30.

As in the Beulah Corridor, loads for individual vehicles were tracked using Oyster card data with origins and destinations inferred using the ODX program. These loads were then scaled up at a route level to meet ETM totals. Vehicle loads at each stop were calculated for all vehicle trips on the ten weekdays in September and October. Those vehicle trips that began during the AM Peak period were used to determine the median AM peak load at each stop along the corridor. Figure 7-3 shows the median loads at each combined stop (those stops served by Route 607 and one or more of the local routes) during the AM peak. Median loads on Route 607 are nearly double the loads on routes 207 and 427 in the middle portion of the corridor. In this middle area, crowding appears to be a serious issue on Route 607 given that the seated capacity on Route 607 is just 62 people. There is also space for 25 standees, resulting in a total capacity of 87 people. With median loads of nearly 80 from

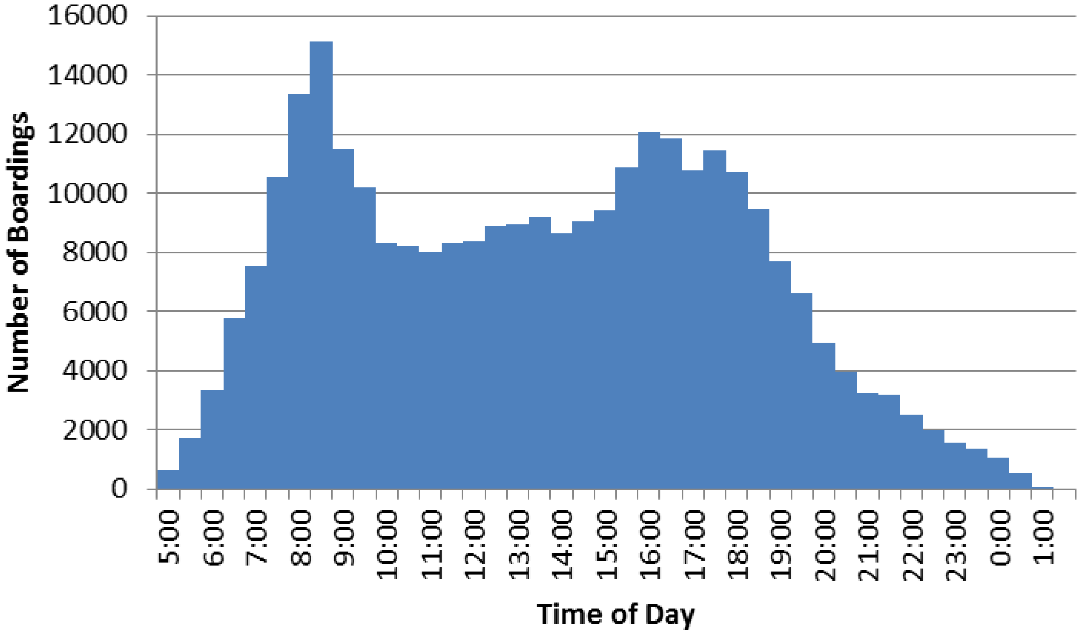



**Figure 3-14:** Uxbridge Inbound Boardings by Time of Day

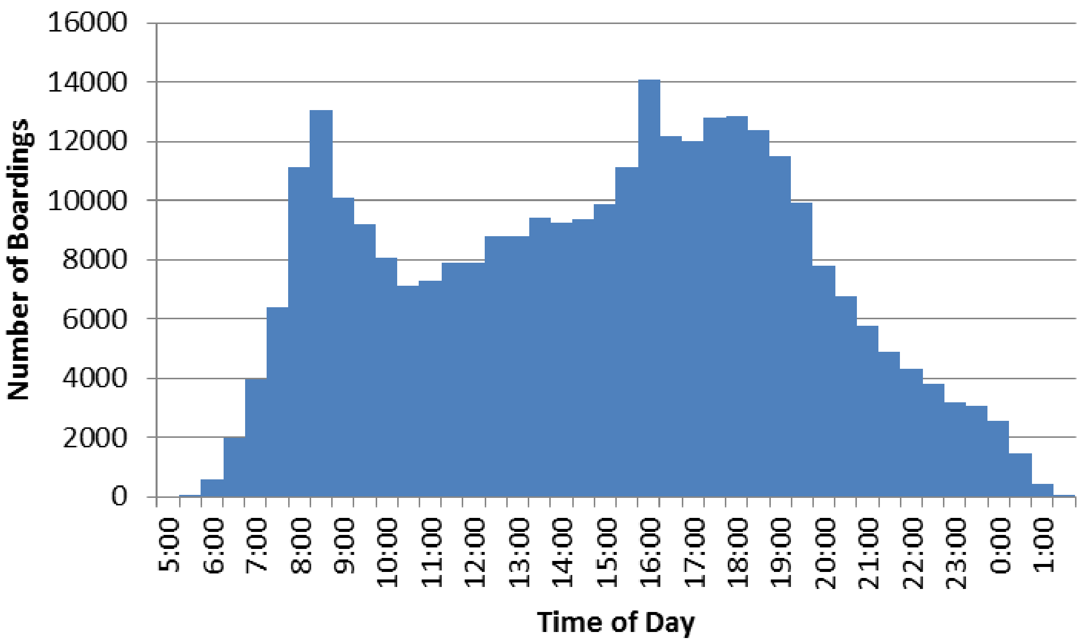



**Figure 3-15:** Uxbridge Outbound Boardings by Time of Day

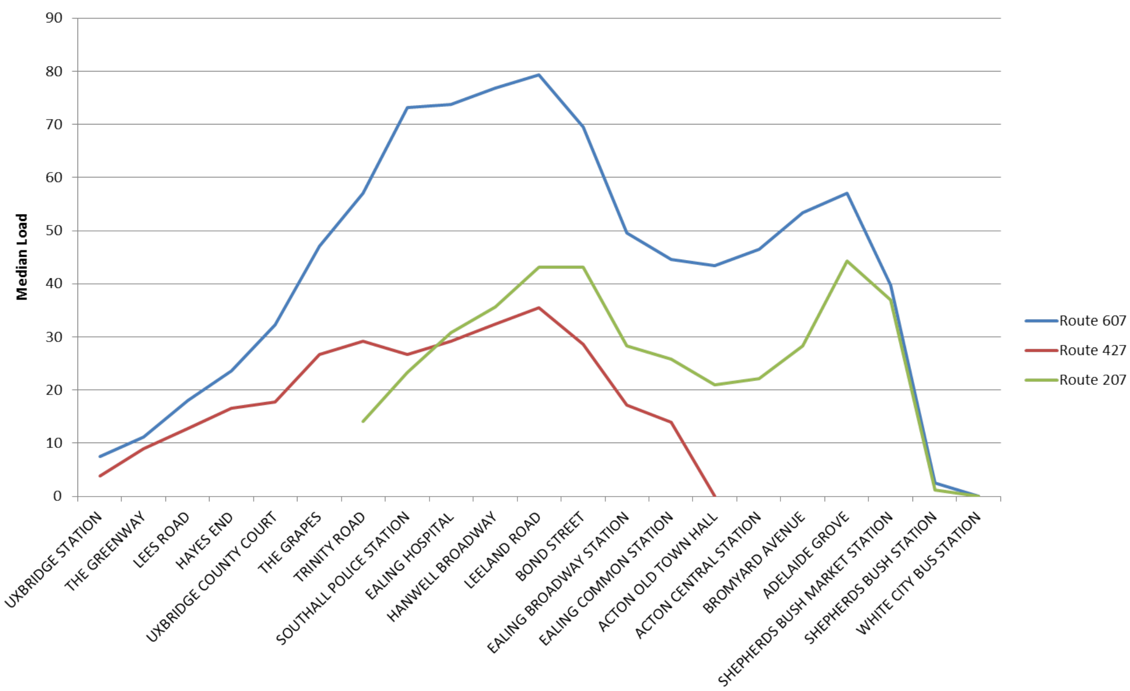



**Figure 3-16:** Uxbridge Inbound AM Peak Loads

Southall Police Station to Bond Street, this suggests that half of the inbound vehicles that arrive at these stops in the AM peak are very near capacity.

Like in the Beulah Corridor, other routes run parallel to these routes, serving some of the same stops and OD pairs. The route choice strategy identification methods are contingent on the set of routes available for an individual to choose between. Therefore, the analysis for the Uxbridge Corridor was restricted to those OD pairs that are served only by routes 207, 427 and/or 607. Table 3.5 shows that this removes about 35% of passenger trips from the analysis. Because parallel routes tend to follow the corridor for short distances, this process removes more shorter-distance OD pairs than longer-distance pairs. However, some shorter OD pairs remain, which can be used for comparison with the longer pairs.

**Table 3.5:** Summary of Uxbridge Corridor Data for Analysis

| | OD Pairs Included | Oyster Trips Over Ten Days | % of Corridor Ridership |
|---|---|---|---|
| Inbound | 2,151 | 290,936 | 62% |
| Outbound | 2,210 | 303,005 | 67% |

## 3.3 Data Sources

Ridership and load data is from ten weekdays at the end of September and the beginning of October in 2012. Oyster data, from the smartcard fare collection system, records the time that an individual taps his or her smartcard to board a bus, as well as the vehicle trip number and route number. This data was processed using the Origin Destination Interchange (ODX) program developed by Gordon (2012) which infers the stop at which these individuals alighted based on their other trips in the system on the same day. On the corridors analyzed, more than 98% of transactions were with smartcards. The ODX program inferred origins and destinations for 77% of these taps on the Beulah Corridor and 81% of taps on the Uxbridge Corridor. For ridership and vehicle load information, these trips are scaled up to meet Electronic Ticket Machine (ETM) data. The ETM data records all boardings regardless of ticket type and including non-paying passengers, such as young children.

Headway information was assessed from posted schedules as well as from Automated Vehicle Location data, called iBus. iBus data records the arrival and departure time of each vehicle from each stop. iBus data was also used to determine the running time between OD pairs.

The final data source used in this research is an online survey. The online survey was sent specifically to registered Oyster users who had provided email address and who used routes 207, 427, and/or 607 between February 4th and 17th, 2013. The survey asked respondents about two recent trips, asking them to identify their starting and ending location, access mode, boarding and alighting stop, the time of day of the trip, their use of real-time arrival information, and the trip purpose. They were also asked questions to identify their route choice strategy and a set of questions about indicators of their attitudes toward crowding, walking time, waiting time, and in vehicle time, their risk aversion, and their level of trust in the information given to them. Finally, they were asked some questions about their demographic characteristics, including age, income, and gender. More information about the survey design and the representativeness of the survey data can be found in Chapter 4.

In conjunction with the survey, Oyster and iBus data for the Uxbridge Corridor from two weeks in February 2013, and ODX-processed Oyster data from one week in February 2013 was used. The ridership patterns for February are similar to those in September and October of 2012. Table 3.6 shows the average daily ridership for the five weekdays in February that were analyzed. In general, ridership is slightly lower than it was in the September/ October days analyzed with the exception of inbound ridership on Route 207 which essentially remained the same.

**Table 3.6:** Uxbridge Corridor Ridership (February 2013)

| | Inbound | Outbound |
|---|---|---|
| Route 207 | 21920<br>*0.0%∗* | 19322<br>*-6.9%∗* |
| Route 427 | 12289<br>*-4.7%∗* | 12391<br>*-0.9%∗* |
| Route 607 | 12020<br>*-3.5%∗* | 11095<br>*-7.9%∗* |

∗ Indicates the % difference of these ridership February figures compared with two weeks in September/October 2012.

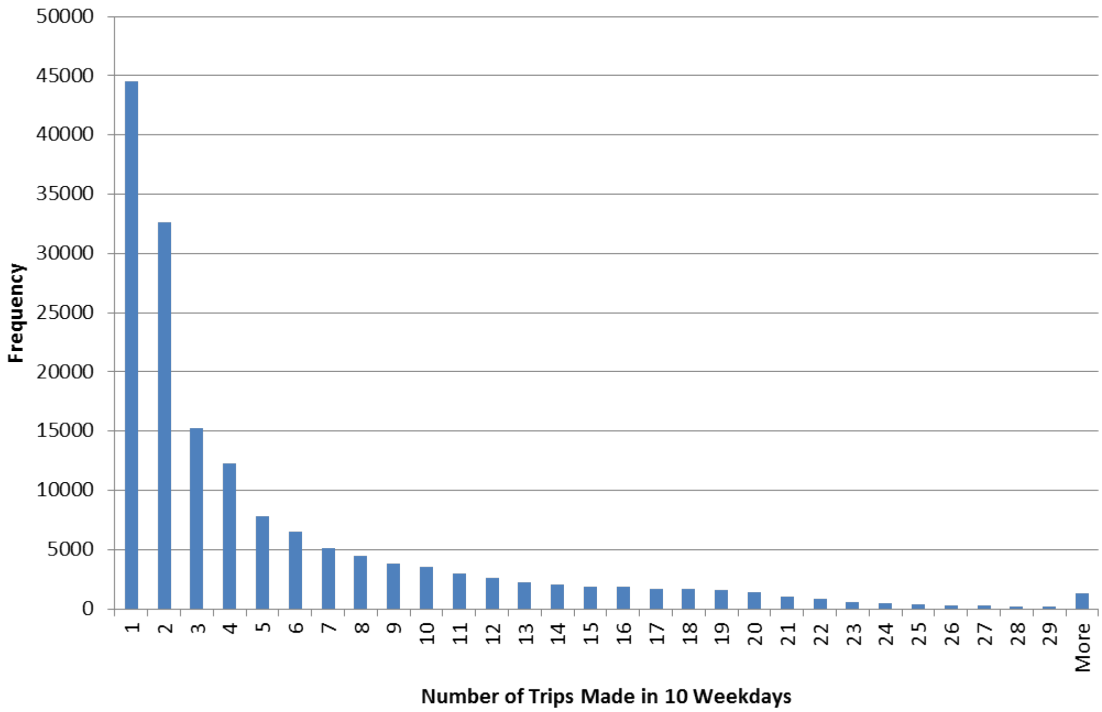



**Figure 3-17:** Frequency of Uxbridge Corridor Use (February 2013)

Table 3.7 shows the mean, median and standard deviation of trip length for the three routes from the February data. These values are almost identical to the values from September and October. At most they differ by .1 km (.06 miles). The pattern of frequency of corridor usage is also very similar to the Fall 2012 data. Figure 3-17 shows the number of passengers who took a given number of trips over ten weekdays in February. The shape is almost identical to Figure 3-12. The reason that the magnitude of passengers is greater in February is that all Oyster taps are included while in the fall data only Oyster taps with inferred origin and destination were considered.

**Table 3.7:** Uxbridge Corridor Trip Lengths by Route (February 2013)

| | Inbound | | | Outbound | | |
|---|---|---|---|---|---|---|
| | Mean | Median | Standard Deviation | Mean | Median | Standard Deviation |
| Route 207 | 2.8 km (1.7 mi) | 2.2 km (1.4 mi) | 2.2 km (1.4 mi) | 3.0 km (1.9 mi) | 2.5 km (1.6 mi) | 2.4 km (1.5 mi) |
| Route 427 | 3.3 km (2.1 mi) | 2.5 km (1.6 mi) | 2.5 km (1.6 mi) | 3.3 km (2.1 mi) | 2.5 km (1.6 mi) | 2.5 km (1.6 mi) |
| Route 607 | 5.7 km (3.5 mi) | 4.6 km (2.9 mi) | 4.1 km (2.5 mi) | 5.9 km (3.7 mi) | 4.9 km (3.0 mi) | 4.2 km (2.6 mi) |

# Chapter 4

# Analysis of Automatically Collected Data

This chapter details three methods to characterize passengers' route choice strategies in a multi-route corridor using only automatically collected data. For simplification, these methods ignore the dynamic properties of plan formation. For example, this analysis does not include a strategy in which passengers plan to wait for a specific route but alter their behavior given real-time information. Passenger strategies are categorized as either first bus (passengers take the first bus that serves their destination) or favorite bus (passengers wait for a bus of a specific route). The three methods employed are empirical analysis, probabilistic modeling, and panel-based analysis.

Both the empirical analysis and the probabilistic model are applied to samples of passengers segmented by trip length. The probabilistic model, which infers passengers strategies based on the headways that preceded their boardings, is also applied to samples that are further-segmented based on stop-level crowding, passenger experience, and the availability of real-time countdown information. The empirical analysis and probabilistic model focus on passengers' decisions once at a stop. The panel analysis sheds light on both the flexibility of passengers' route choice once at a stop, and also on their flexibility of their stop selection. Each method is explained and then followed with the results for the Beulah and Uxbridge Corridors.

## 4.1 Empirical Analysis Methodology

The empirical analysis uses bus arrival times to estimate the proportion of time in a given time period (such as the AM peak) that each bus is the first bus to arrive. Bus arrivals of all routes in the choice set at a given stop are considered, as in Figure 4-1. Each color represents a different bus route. To calculate the proportion of time the green route is the first bus to arrive, the length (in time) of all green segments is summed, and divided by the total time period being considered. This represents the proportion of passengers expected to board the green route under the assumption that passengers board the first bus that serves their destination.


**Figure 4-1:** Schematic of Bus Arrivals at a Stop

These expected proportions are then compared to the actual proportions of passengers who boarded each route during that time period. Under the assumption of a constant mean passenger arrival rate at any stop, if all passengers boarded the first bus serving their destination, these proportions would be identical. A constant mean arrival rate means that the average arrival rate within each headway in the period analyzed is the same. Thus, the number of arrivals is proportional to the length of the headway. If the expected proportions under these assumptions are not identical to the actual proportions of passengers who board each route, either some passengers do not board the first bus that serves their destination, or the mean arrival rate is not constant across the period.

## 4.2 Empirical Analysis Results

### 4.2.1 Beulah Corridor

The empirical analysis was performed on the stop in each direction that had the greatest number of boardings in the analysis data set. The analysis data set excludes OD pairs that are served by additional parallel routes, other than Route 196 and Route 468. It also excludes trips in which the boarding or destination stops are geographically offset (not shared) between the two routes under study.

The Crown Point/ Knight's Hill stop was selected in the inbound direction. The analysis was restricted to the AM peak period, to ensure that the assumption of a constant mean arrival rate would be more more realistic. The AM peak period was selected, as described in Section 3.1 by plotting a histogram of boardings over 30-minute time periods throughout the day, with boardings summed over ten weekdays. In the inbound direction, the AM peak was determined to last from 7:00 AM to 9:30 AM. 649 passengers boarded at this stop in the AM peak period and had a destination served by only routes 196 and 468.

In the outbound direction, the Norwood Road/ Robson Road stop was selected. Based on the histogram of boardings, the AM peak period was determined as 7:30 AM to 9:30 AM. During this period, in the ten weekdays analyzed, 529 people took trips on routes 196 and 468 that were served exclusively by these two routes.

For each direction, iBus data provides actual bus arrivals at the boarding stop for the AM peak period for ten days in the fall of 2012. This data was used to calculate the expected proportions. The actual proportions were determined using Oyster data processed through the ODX period for the same period and days. Table 4.1 shows the expected proportions compared to the actual proportions of passengers that boarded each route. In both directions, the actual proportion of passengers on Route 196 is slightly greater than expected. However, the differences between the actual proportions and the expected proportions are very small: less than .03 for both routes in both directions. The close match between expected and actual proportions suggests that a first bus strategy is dominant along the corridor.

**Table 4.1:** Empirical Analysis Results for the Beulah Corridor

| | Inbound | | Outbound | |
|---|---|---|---|---|
| | Route 196 | Route 468 | Route 196 | Route 468 |
| Expected Proportion | 0.431 | 0.569 | 0.372 | 0.628 |
| Actual Proportion | 0.458 | 0.542 | 0.389 | 0.611 |

### 4.2.2 Uxbridge Corridor

For the Uxbridge Corridor in the inbound direction, trips from Southall Police Station were analyzed. This stop was selected because it had a substantial number of boardings with trips of varied distances. The analysis focuses on the AM peak period, determined based on a histogram of boardings over time (see Section 3.2). For the inbound direction, the AM peak period was designated as 7:00 AM to 9:30 AM.

This research hypothesized that route choice decisions would vary depending on the length of the trip on the Uxbridge Corridor. For longer trips, the in-vehicle time savings of taking Route 607, the limited stop route, are greater than for shorter trips. This suggests that passengers with longer trips will be more likely to wait for a limited stop bus. The distribution of trip length by service type (see Section 3.2) confirms this theory by showing that longer trips are far more likely to be taken on Route 607 than shorter trips. To measure this variation, the actual proportions were calculated for a set of samples of passengers defined by these passengers' destination stops.

Table 4.2 shows the expected proportions under the first bus assumption (calculated from iBus data) compared to the actual proportions (determined from ODX-processed Oyster data) for two samples. These samples consist of passenger trips from Southall Police Station to destinations served by all three of the Uxbridge Corridor routes: 207, 427, and 607, and not served by additional parallel routes. Table 4.3 lists the destination stops considered in each sample and the expected in-vehicle travel time on the local and limited stop routes.

**Table 4.2:** Empirical Analysis Results for Uxbridge Inbound Samples in the Three-Route Market

| | Route 207 | Route 427 | Route 607 |
|---|---|---|---|
| First Bus Proportions | 0.528 | 0.240 | 0.232 |
| Sample 1 | 0.378 | 0.167 | 0.455 |
| Sample 2 | 0.300 | 0.215 | 0.486 |

The first sample consists of trips during the AM peak from Southall Police Station to Leeland Road. This trip takes approximately 14 minutes on routes 207 or 427 and 11 minutes on Route 607. The second sample is composed of trips from Southall Police Station to Ealing Broadway Station. The trip time is approximately 23 minutes on the local routes and 19 minutes on Route 607. For the longer trip, the proportion of passengers selecting Route 607

**Table 4.3:** Characteristics of the Four Inbound Samples

| | Destination Stop(s) | Travel Time, Local (minutes) | Travel Time, Limited Stop (minutes) | Sample Size |
|---|---|---|---|---|
| Sample 1 | Leeland Road | 13.8 | 11.2 | 323 |
| Sample 2 | Ealing Broadway Station | 23.2 | 18.9 | 1328 |
| Sample 3 | Acton Central Station | 38.9 | 32.0 | 102 |
| Sample 4 | Shepherds Bush Market, Shepherds Bush, and White City Bus Stations | 56.6 | 46.7 | 941 |

is greater. The proportion of passengers using Route 207 is smaller for the longer trip, but the proportion of passengers selecting Route 427 increases for the longer trip, contrary to expectations that the local routes would be less desirable for longer trips. Further analysis considers other explanatory factors that may cause this behavior. Overall, the deviation of the actual proportions from the expected proportions under the first bus assumption indicate that some passengers on the corridor do not have a first bus strategy. In addition, the tendency of passengers to prefer Route 607 increases with the length of the trip.

Some passengers boarding at Southall Police Station travel to destinations served only by routes 207 and 607. For passengers in this two-route market, the expected proportions of passengers who would board each route under the first bus assumption were calculated based on arrivals of these two routes only. Two samples from this market were analyzed. Sample 3 consists of passengers traveling from Southall Police Station to Acton Central Station. This trip takes about 39 minutes on the local route and 32 minutes on the limited stop route. Sample 4 is made up of passengers who made trips from Southall Police Station to one of the the three final consecutive stops served by these two routes: Shepherds Bush Market Station, Shepherds Bush Station, and White City Bus Station. These trips take approximately 57 minutes on Route 207 and 47 minutes on Route 607. Table 4.4 shows the expected proportions under the first bus assumption and the actual proportions for this sample. For these longer trips, there is a very strong preference for Route 607, with 86% of passengers in Sample 3 selecting Route 607 and 91% of passengers in Sample 4 selecting the limited stop buses.

**Table 4.4:** Empirical Analysis Results for Uxbridge Inbound Samples in the Two-Route Market

| | Route 207 | Route 607 |
|---|---|---|
| First Bus Proportions | 0.705 | 0.295 |
| Sample 3 | 0.147 | 0.853 |
| Sample 4 | 0.090 | 0.910 |

Considering all four inbound samples, there is a clearly increasing trend in the proportion of passengers taking Route 607 as the trip length increase. This confirms the hypothesis that passengers change their behavior with trip length, and are more likely to choose Route

607 for longer trips. For the shortest trip, considered in Sample 1, just 46% of passengers took Route 607. For the longest trips analyzed in Sample 4, 91% of trips were made on Route 607. The deviation from the expected proportions under the first bus assumption grows as trips lengthen. However, even for the shortest trips, the actual proportions of passengers boarding each route are substantially different from the expected proportions. This suggests that even for short trips, not all passengers use a first bus strategy.

In the outbound direction, trips from the Christchurch stop were analyzed. Again, this stop was selected because of the large number of boardings with trips to stops at varied distances along the corridor. Based on a histogram of boardings over time, the AM peak period was determined to last from 7:30 AM to 9:30 AM (see Section 3.2). Two OD pairs within the three-route market (passengers can take routes 207, 427 or 607) were analyzed. Table 4.5 summarizes the route choices of these samples compared to the expected proportions based on departures of vehicles from the Christchurch stop, assuming passengers board the first bus that serves their destination. Table 4.6 summarizes the characteristics of the samples in the outbound direction, including destination stops and expected in-vehicle travel time.

**Table 4.5:** Empirical Analysis Results for Uxbridge Corridor Outbound Samples in the Three-Route Market

| | Route 207 | Route 427 | Route 607 |
|---|---|---|---|
| First Bus Proportions | 0.478 | 0.326 | 0.197 |
| Sample 1 | 0.396 | 0.219 | 0.385 |
| Sample 2 | 0.288 | 0.146 | 0.567 |

**Table 4.6:** Characteristics of the Four Outbound Samples

| | Destination Stop | Travel Time, Local (minutes) | Travel Time, Limited Stop (minutes) | Sample Size |
|---|---|---|---|---|
| Sample 1 | Ealing Hospital | 11.5 | 9.7 | 384 |
| Sample 2 | Southall Police Station | 16.7 | 13.6 | 233 |
| Sample 3 | The Grapes | 27.2 | 22.3 | 49 |
| Sample 4 | The Greenway | 47.1 | 37.7 | 85 |

Sample 1 is composed of passengers traveling form Christchurch to Ealing Hospital. This trip takes 12 minutes on the local routes and 10 minutes on Route 607. Sample 2 is a slightly longer OD pair, from Christchurch to Southall Police Station. This trip is 17 minutes on the local routes and 14 minutes on the limited stop route. A greater proportion of the passengers on this longer trip take Route 607, although even for the short trip taken by passengers in Sample 1, the proportion of passengers selecting Route 607 is greater than would be expected under the first bus assumption. This implies that a first bus strategy is not always used by passengers, even for short trips, but the deviation from the first bus strategy grows as trips lengthen.

Longer trips from Christchurch are served only by routes 427 and 607. Table 4.7 displays the results for two samples from this two-route outbound market. Sample 3 shows passengers traveling to The Grapes (27 minutes on Route 427 and 22 minutes on Route 607) and Sample 4 is composed of passengers traveling from Christchurch to the Greenway, which is 47 minutes on Route 427 and 38 minutes on Route 607. In Sample 3, the proportion of passengers using Route 607 grows to 80%, and in Sample 4, 97% of passengers select Route 607. This indicates a substantial deviation from the expected proportions under the first bus assumptions. This suggests that for these long trips, very few passengers use a strategy of boarding the first bus that serves their destination and many passengers wait specifically for the limited stop service route.

**Table 4.7:** Empirical Analysis Results for Uxbridge Corridor Outbound Samples in the Two-Route Market

| | Route 427 | Route 607 |
|---|---|---|
| First Bus Proportions | 0.610 | 0.390 |
| Sample 3 | 0.204 | 0.796 |
| Sample 4 | 0.035 | 0.965 |

The results from all four outbound samples show that as trip lengths increase, the preference for Route 607 increases, growing from 39% of passengers selecting the route in Sample 1 to 97% of Sample 4 electing to ride Route 607. In all samples, there is a deviation from the expected proportions under the first bus assumption that implies that favorite bus strategies exist even for short trips and these favorite bus strategies become more and more prevalent as trip length increases.

## 4.3 Empirical Analysis Conclusions

The empirical analysis implies that on the Beulah Corridor, the first bus strategy is dominant, while this is not the case on the Uxbridge Corridor. On the Uxbridge Corridor, the deviation from the expected proportions implied by a first bus strategy grows larger as the trip length increases. This indicates that passengers are less likely to board the first bus that serves their destination as their trips become longer. This is logical because the time savings of waiting for a Route 607 bus increase as the trip length increases.

Given the availability of accurate AVL data documenting arrivals at a stop, this method is easy to apply. However, finding a period of time that has a relatively constant mean arrival rate and is long enough to include a sufficient sample size of passengers can be difficult. Within the traditional analysis periods, such as the AM peak period, there is usually a peak-of-the-peak period when arrivals occur at a higher rate than during the rest of the period. This means that while deviations from the expected proportions under the first bus assumption strongly suggest that passengers are not using a first bus strategy, it is possible that some or all of the deviation is due to passengers' varied arrival rates.

In addition, this method does not provide direct estimates of the proportion of passengers with each strategy, but rather is a good first pass to reveal general trends in the data. Actual values for the proportions of passengers with each strategy are needed to calculate metrics such as passenger waiting time, taking into account route choice strategies. Estimates of the proportions of passengers with each strategy can also be used in demand assignment models.

Another weakness of this method is its failure to provide information about individual behavior. For example, if one passenger always uses Route 196 only, while another passenger uses Route 468 exclusively, these strategies would essentially balance out and would not be detected by this analysis method.

## 4.4 Probabilistic Model Methodology

The probabilistic model assumes a constant mean arrival rate only in the route-specific headway immediately preceding a given boarding. The model uses the fact that passengers with a first bus strategy must have arrived during the combined headway preceding the vehicle they boarded. By contrast, passengers with a favorite bus strategy may have arrived at any time during the route-specific headway preceding the bus they boarded. Figure 4-2 shows the route-specific and combined headways.

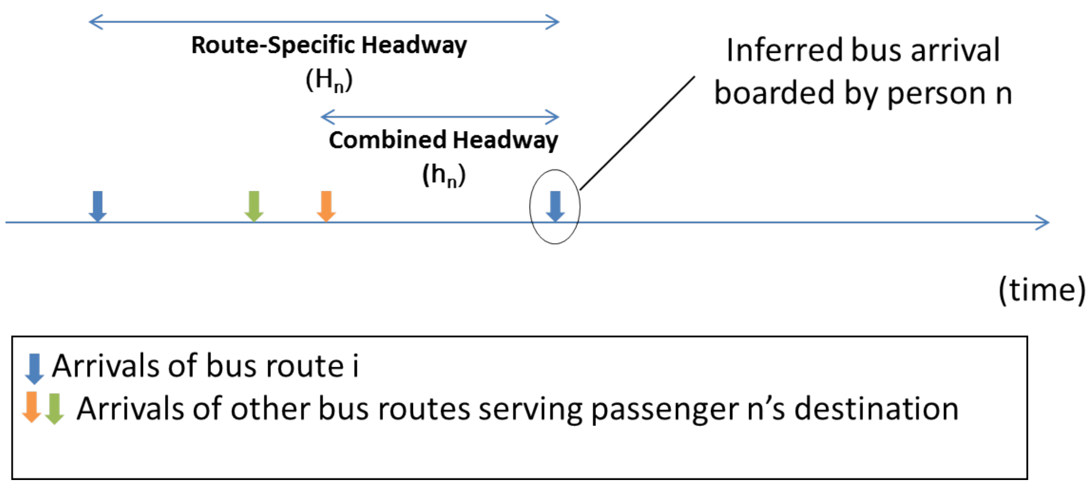



**Figure 4-2:** Diagram of Headways Used in the Probabilistic Model

The model then uses the relative lengths of the headways to determine the probability of an observed bus boarding given these headways and given probabilities for first bus and favorite bus strategies in the population. As shown in Figure 4-3, passenger $n$ can board route $i$ in two different contexts. Following the left branch, the passenger may have a first bus strategy and route $i$ happens to be the first route to arrive. Alternatively, the passenger may have a favorite bus strategy, following the right branch, and favoring route $i$.

Given this decision tree, the probability that passenger $n$ boards route $i$ can be written as

$$\text{Probability that passenger } n \text{ boards route } i = p\left(\frac{h_n}{H_n}\right) + (1-p)q_i \qquad (4.1)$$

where $p$ is the probability that passengers have a first bus strategy and $q_i$ is the probability that passengers favor route $i$, given that they have a favorite bus strategy. $h_n$ is the combined headway and $H_n$ is the route-specific headway.

Then, the probability of a favorite and a first bus strategy are estimated by finding the

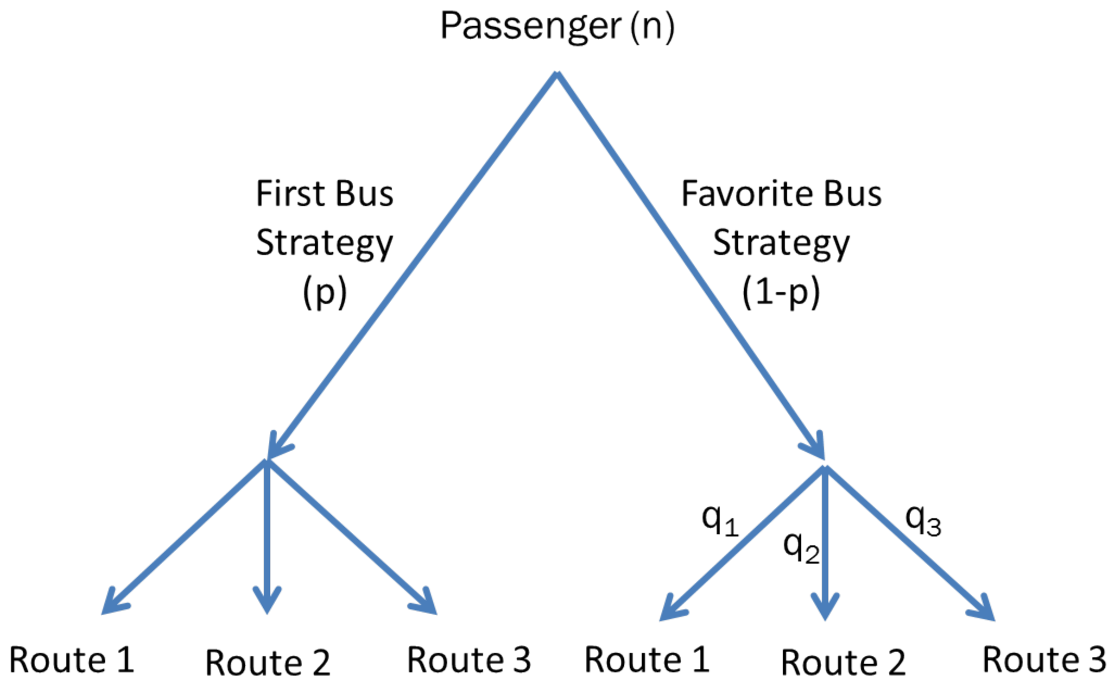



**Figure 4-3:** Decision Tree for an Individual Choosing Between Three Routes

values that maximize the log likelihood function for all passengers.

$$\text{Log Likelihood} = \sum_{n=1}^{N} log\left(p\left(\frac{h_n}{H_n}\right) + (1-p)\sum_{i=1}^{I} q_i * C_{in}\right) \tag{4.2}$$

$N$ is the number of passengers and there are $I$ routes to select from. $C_{in}$ is a dummy variable that takes a value of one if individual $n$ boarded bus route $i$ and zero otherwise.

This model assumes a constant mean arrival rate in the preceding same-route and combined headway for each boarding, but these rates can vary for the headways preceding other boardings in the period of analysis. Therefore it is no longer necessary to assume a constant arrival rate over an entire two-hour (or longer) period, as was done in the empirical analysis. This model uses the method of maximum likelihood estimation to determine the proportions of the population with each strategy that are most likely to produce the observed boardings, given the arrivals of buses at the stop.

An alteration to the definition of $h_n$ and $H_n$ is made to account for the distortion of passenger strategies that can occur with near-simultaneous arrivals of buses. Assuming that passengers with a first bus strategy must have arrived in the very small headway between two bunched bus arrivals because they happened to board the second bus is unreasonable. For example, a passenger may board the second bus because it pulls up closer to them, not because they were waiting for it, making this choice fit closer with a first bus strategy than a favorite bus strategy. Therefore, a “bunch” threshold of 30 seconds was set. If a previous bus arrived inside the threshold, the first applicable arrival outside of the threshold was used to determine the combined or same route headway.

## 4.5 Probabilistic Model Results

### 4.5.1 Beulah Corridor

The probabilistic model is applied to the same samples as the empirical analysis. In the Beulah Corridor, all inbound AM peak trips from Crown Point/ Knight's Hill and all outbound AM peak trips from Norwood Road/ Robson Road were analyzed. In each direction, only passengers traveling to destinations served by routes 196 and 468 exclusively were considered. Records with headways of more than 21 minutes were discarded as these are more than 1.75 times the scheduled headway, and may be the result of missing iBus data. Table 4.8 shows the results of the maximum likelihood estimation. About 4% of inbound passengers are found to have a preference for Route 196. In the outbound direction, all passengers were estimated to have a first bus strategy.

**Table 4.8:** Probabilistic Model Applied to the Beulah Corridor Empirical Analysis Samples

| | First Bus Strategy | Favorite Bus: Route 196 | Favorite Bus: Route 468 |
|---|---|---|---|
| Inbound | 0.961 | 0.039 | 0.000 |
| Outbound | 1.000 | 0.000 | 0.000 |

These results are consistent with the results from the empirical analysis, which showed a closer match between the actual and expected proportions in the outbound than in the inbound direction. To test the validity of the probabilistic model, the strategies from Table 4.8 can be used to assign demand for the sample. The proportion of the sample that was estimated to have a first bus strategy is assigned to the two routes according to the expected proportions from the empirical analysis. The proportion of passengers estimated to favor Route 196 are all assigned to Route 196. Table 4.9 shows the predicted proportions using this methodology. These predicted proportions match the actual proportions more closely than the expected proportions under the assumption that all passengers use a first bus strategy.

**Table 4.9:** Test of the Probabilistic Model for Demand Assignment in the Beulah Corridor

| | Inbound | | Outbound | |
|---|---|---|---|---|
| | Route 196 | Route 468 | Route 196 | Route 468 |
| Predicted Proportion | 0.453 | 0.547 | 0.372 | 0.628 |
| Actual Proportion | 0.458 | 0.542 | 0.389 | 0.611 |

Because the probabilistic model approach assumes a constant mean arrival rate only within a given boarding's preceding headway, it can be applied to all trips in the corridor, regardless of boarding stop and time of day (trips served by routes other than Route 196 and Route 468 or that begin or end at geographically offset stops remain exlcuded). The results for all trips on the corridor at all times of day are found in Table 4.10. Again, they confirm the predominance of a first bus strategy on the corridor.

Table 4.10: Results of the Probabilistic Model for all Trips in the Beulah Corridor

| | First Bus Strategy | Favorite Bus: Route 196 | Favorite Bus: Route 468 |
|---|---|---|---|
| Inbound | 0.982 | 0.009 | 0.008 |
| Outbound | 1.000 | 0.000 | 0.000 |

To attempt to discover variation in passenger strategies on the Beulah Corridor, the model is applied to AM peak trips only. As was found in the sample used for the empirical analysis, this sample, which includes additional boarding stops in the corridor during the same AM peak time period, shows some existence of favorite bus strategies in the inbound direction, but not in the outbound direction. Table 4.11 summarizes these results.

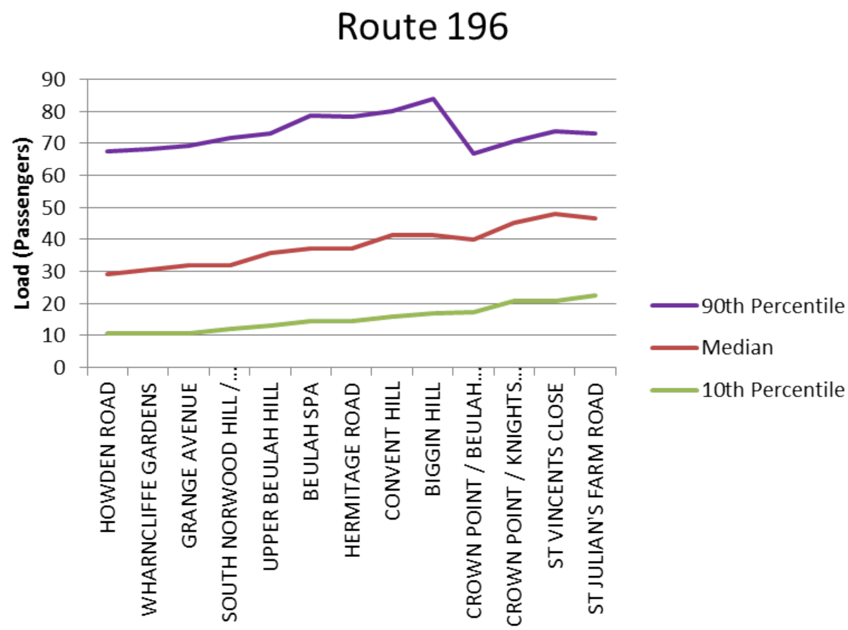
Table 4.11: Results of the Probabilistic Model for all AM Peak Trips in the Beulah Corridor

| | First Bus Strategy | Favorite Bus: Route 196 | Favorite Bus: Route 468 |
|---|---|---|---|
| Inbound | 0.921 | 0.050 | 0.029 |
| Outbound | 1.000 | 0.000 | 0.000 |

### Crowding

The difference in behavior in the two directions, particularly in the AM peak, merits further consideration. This pattern of behavior could be due to the differences in vehicle loads for the two directions. Figures 4-4 and 4-5 show the median, tenth percentile, and ninetieth percentile loads for each route in the inbound and outbound direction. As expected, loads are higher in the inbound direction for both routes. Both routes have high 90th percentile loads in the inbound direction in the first half of the corridor from Howden Road to West Norwood Station. This crowding may cause passengers to choose to wait for less crowded buses when boarding in this corridor, accounting for the nearly 8% of passengers who were estimated to have a favorite bus strategy.

To further analyze the impact of crowding on behavior, the strategies of passengers boarding at each stop in the inbound direction were estimated to determine if the prevalence of favorite bus strategies was correlated with crowding. Figure 4-6 shows the percentage of passengers boarding at each stop that were estimated to have a first bus strategy. If crowding influences behavior, this percentage would be inversely correlated with the crowding levels in Figure 4-4. However, no clear pattern is observed. The stops with the lowest proportion of first bus strategy are Wharncliffe Gardens, Biggin Hill, South Norwood Hill, and Upper Beulah Hill. With the exception of Biggin Hill, these stops are not significantly more crowded than other stops along the shared segment. The least crowded stops on the shared segment are Crown Point/ Beulah Hill and St. Julian's Farm Road. While 100% of passengers boarding at St. Julian's Farm Road were estimated to have a first bus strategy, only 88% of passegers at Crown Point/ Beulah Hill were estimated to board the first bus. Thus, the behavior at St. Julian's Farm Road and Biggin Hill support the hypothesis that



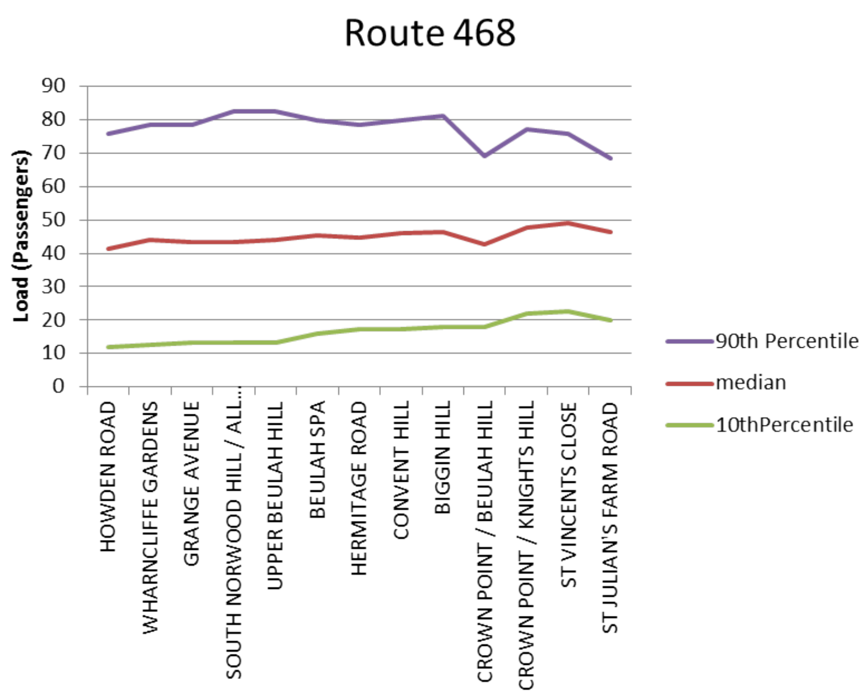
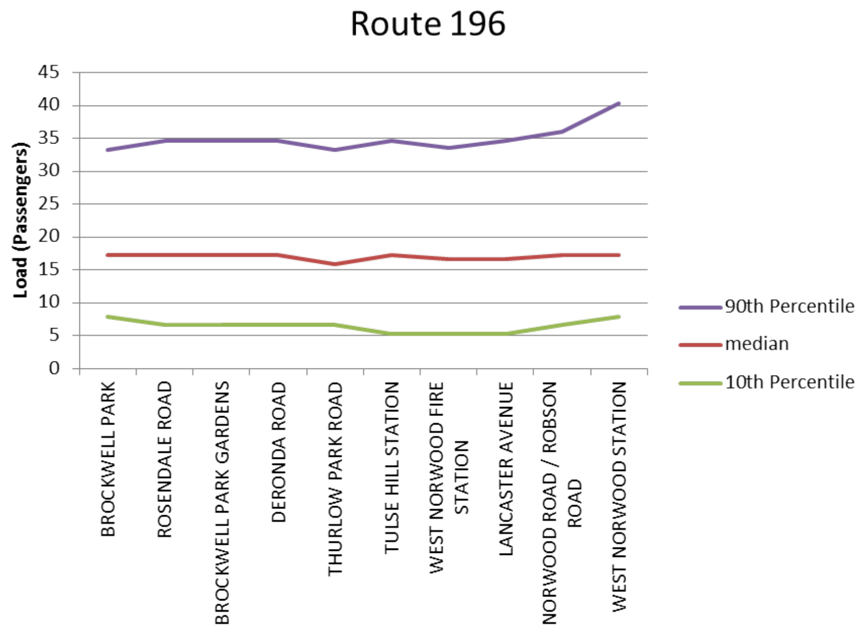




**Figure 4-4:** Beulah Corridor AM Peak Inbound Loads

crowding plays an important role, but when considering all stops, the relative impact of crowding on various inbound stops is not clear.

The failure to observe a definitive pattern may be due to error in the strategy estimates resulting from relatively small sample sizes. Three of the boarding stops had less than 100 boardings over ten days in the AM peak. In addition, the variation of loads between stops



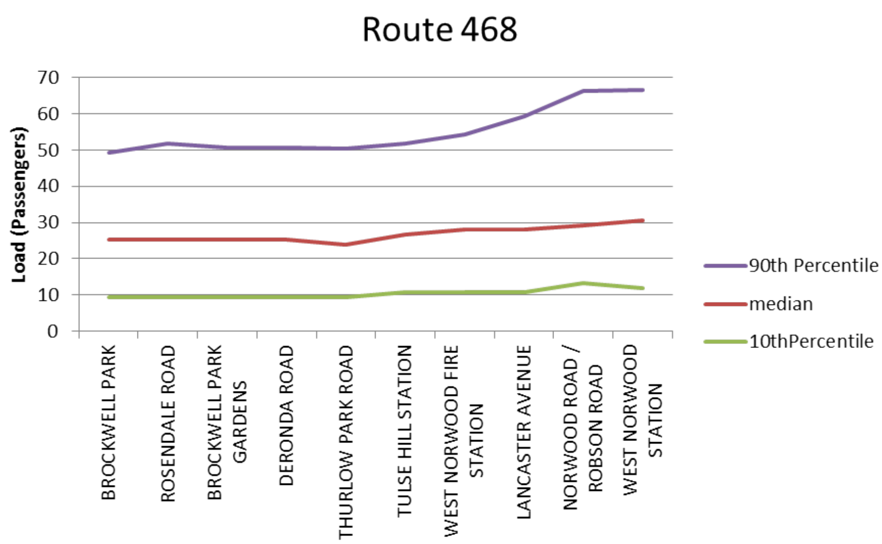




**Figure 4-5:** Beulah Corridor AM Peak Outbound Loads

is not very significant. Much more significant are the differences in loads for the stops in the inbound direction from the stops in the outbound direction. All stops in the outbound direction have median and 90% loads that are lower than even those at the least crowded stops in the inbound direction. Therefore, despite the ambiguity of the behavior at a stop-by-stop level of analysis, it is likely that the differences in behavior in the inbound and outbound directions is due to the difference in crowding by direction.

In the outbound direction, loads are consistently below 70 passengers. While Norwood Road/ Robson Road and West Norwood Station have loads that are somewhat higher than the other boardings stops, median loads remain at 30 passengers or lower. Like all outbound

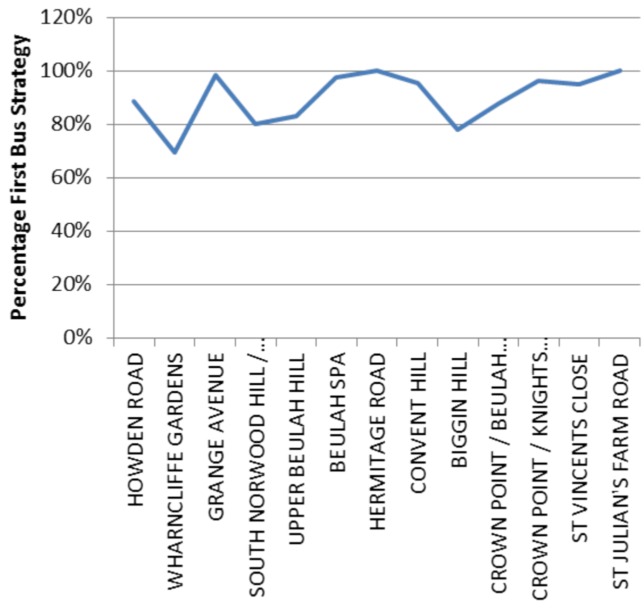



**Figure 4-6:** Beulah Corridor Proportion First Bus Strategy by Boarding Stop

AM peak passengers, 100 % of passengers boarding at these stations were estimated to have first bus strategies.

### Frequency of Corridor Use

Another factor that may influence a passenger's behavior on the corridor is his or her level of familiarity with the corridor, in this case measured by the number of trips the individual has taken on the corridor in the ten days analyzed. Passengers with six or more trips in a given direction during the ten-day period are deemed frequent users, while passengers with just one trip in a given direction are infrequent users. The patterns of behavior of frequent and infrequent users are different in the inbound and outbound directions. In the inbound direction, frequent users (those with six or more trips in a given direction in the ten week days analyzed) were less likely to take the first bus than infrequent users (passengers with only one trip in a given direction in the ten weekdays). In the outbound direction, frequent users were more likely to take the first bus than infrequent users. Table 4.12 shows these results. One expects frequent users of the corridor to have more knowledge of the corridor than infrequent users. They are likely aware that both routes serve their destination, while one-time users may not be. This could explain the pattern observed in the outbound direction. While 100% of frequent users in the outbound direction were estimated to take the first bus, only 93.4% of infrequent users are estimated to board the first bus. The infrequent users may not be aware that they can board either bus. In the inbound direction, however, the opposite is observed. If crowding is causing some people to not board the first bus in the inbound direction, this would indicate that frequent users are more sensitive to crowding than infrequent users. Frequent users may be more aware of the level of service on the corridor and of the variation in passenger loads on vehicles and thus feel more confident waiting for a less crowded bus.

**Table 4.12:** Beulah Corridor Strategies by Frequency of Corridor Use

| | Frequent Users | | | |
|---|---|---|---|---|
| | First Bus Strategy | Favorite Bus: Route 196 | Favorite Bus: Route 468 | Sample Size |
| Inbound | 0.945 | 0.026 | 0.029 | 1619 |
| Outbound | 1.000 | 0.000 | 0.000 | 2885 |
| | Infrequent Users | | | |
| | First Bus Strategy | Favorite Bus: Route 196 | Favorite Bus: Route 468 | Sample Size |
| Inbound | 0.992 | 0.008 | 0.000 | 2299 |
| Outbound | 0.934 | 0.008 | 0.057 | 2826 |

### 4.5.2 Uxbridge Corridor

On the Uxbridge Corridor, the probabilistic model is first applied to the same eight samples that were analyzed using the empirical method. All inbound samples consist of passengers who boarded at Southall Police Station and all outbound samples consist of people who boarded at Christchurch. Each sample includes passengers with specific destination stops, with the trip lengths increasing as the sample number increase. Tables 4.3 and 4.6 summarize the sample characteristics. These samples are used to test the validity of the probabilistic model for the Uxbridge Corridor by using the estimated strategies for the samples to allocate demand and comparing this to the the actual proportions of passengers in each sample who took each route.

Then, the analysis is broadened to include all OD pairs in the corridor that are served by Route 607 and one or both of the local routes (routes 207 and 427). OD pairs that are served by additional parallel routes are excluded as are trips to or from stops that are geographically offset (the stops for the routes are not shared). The majority of the stops served by Route 607 have countdown signs that display the number of minutes until approaching buses will arrive. Two stops, Hanwell Broadway and Ealing Broadway, do not have these signs. For the majority of the analysis, boardings at these stops were removed to attempt to control for access to information. Then, the boardings of passengers at these two stops were analyzed and compared to boardings at similar stops that have countdown information.

The analysis focuses on inbound boardings in the AM peak and evaluates the impacts of trip length, crowding, frequency of ridership, and access to bus arrival information. To conduct the analysis passengers must be grouped according to the bus routes they are able to take for their trip. Therefore, the analysis considers three markets. The first market consists of passengers traveling between OD pairs served by routes 427 and 607 only. The second market is made up of passengers traveling between OD pairs served by routes 207 and 607 only. Market 3 consists of passengers making trips on OD pairs served by routes 207, 427, and 607, exclusively. For all the probabilistic analysis boardings with headways that were considered outliers were removed[1].

[1]Outliers were determined by first calculating the inter-quartile range (IQR) for all headways. The IQR is the 75th percentile value less the 25th percentile value. Any values that were greater than the 75th

### Sample Analysis

Tables 4.13 and 4.14 show the results for the four inbound and four outbound samples. As the empirical analysis suggested, passengers are more likely to prefer Route 607 for the samples that consist of longer trips. For these eight samples, virtually no passengers were estimated to prefer Route 207 or Route 427. This suggests that factors such as crowding or lack of route knowledge are not influencing passengers to prefer the local routes once they have already decided to board and alight at stops served by Route 607, for these particular OD pairs.

**Table 4.13:** Probabilistic Model Results for Uxbridge Inbound Samples

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 427 | Favorite Bus: Route 607 |
|---|---|---|---|---|
| Sample 1 | 0.764 | 0.000 | 0.000 | 0.236 |
| Sample 2 | 0.752 | 0.000 | 0.010 | 0.243 |
| Sample 3 | 0.229 | 0.000 | NA | 0.771 |
| Sample 4 | 0.171 | 0.000 | NA | 0.829 |

**Table 4.14:** Probabilistic Model Results for Uxbridge Outbound Samples

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 427 | Favorite Bus: Route 607 |
|---|---|---|---|---|
| Sample 1 | 0.878 | 0.000 | 0.000 | 0.122 |
| Sample 2 | 0.708 | 0.000 | 0.000 | 0.292 |
| Sample 3 | 0.609 | NA | 0.000 | 0.391 |
| Sample 4 | 0.159 | NA | 0.000 | 0.841 |

The results for these eight samples are tested by using the estimated strategies to predict the proportion of passengers who would use each route. Passengers who are estimated to have a first bus strategy are allocated to the routes in the proportions derived from the empirical analysis of the iBus arrivals, deemed the first bus proportions. Table 4.15 shows these results for the four inbound samples and Table 4.16 shows the predictions for the outbound samples. The strategies inferred from the probabilistic model predict proportions that are much closer to the actual proportions than the expected proportions under the first bus assumption were. However, in all samples in both directions, the model results underestimate the proportion of passengers on Route 607, while overestimating the passengers on the local routes. One possible explanation for this is that passengers are timing their arrival at the stop to coincide with a Route 607 bus arrival. Therefore, the arrival rate within the headways preceding the Route 607 boardings is not constant, as the probabilistic model assumes.

percentile plus 1.5 times IQR were deemed outliers.

**Table 4.15:** Test of the Probabilistic Model for Demand Assignment in the Uxbridge Corridor (Inbound)

| | Route 207 | Route 427 | Route 607 |
|---|---|---|---|
| Sample 1 | | | |
| Predicted Proportions | 0.403 | 0.183 | 0.419 |
| Actual Proportions | 0.378 | 0.167 | 0.455 |
| Sample 2 | | | |
| Predicted Proportions | 0.397 | 0.180 | 0.423 |
| Actual Proportions | 0.300 | 0.215 | 0.486 |
| Sample 3 | | | |
| Predicted Proportions | 0.161 | NA | 0.839 |
| Actual Proportions | 0.147 | NA | 0.853 |
| Sample 4 | | | |
| Predicted Proportions | 0.121 | NA | 0.879 |
| Actual Proportions | 0.090 | NA | 0.910 |

**Table 4.16:** Test of the Probabilistic Model for Demand Assignment in the Uxbridge Corridor (Outbound)

| | Route 207 | Route 427 | Route 607 |
|---|---|---|---|
| Sample 1 | | | |
| Predicted Proportions | 0.420 | 0.286 | 0.295 |
| Actual Proportions | 0.396 | 0.219 | 0.385 |
| Sample 2 | | | |
| Predicted Proportions | 0.338 | 0.231 | 0.431 |
| Actual Proportions | 0.288 | 0.146 | 0.567 |
| Sample 3 | | | |
| Predicted Proportions | NA | 0.371 | 0.629 |
| Actual Proportions | NA | 0.204 | 0.796 |
| Sample 4 | | | |
| Predicted Proportions | NA | 0.097 | 0.903 |
| Actual Proportions | NA | 0.035 | 0.965 |

### Trip Length

Next, all OD pairs are considered, grouped by market. Within each market, OD pairs were segmented according to the trip length in minutes on Route 607. Tables 4.17, 4.18, and 4.19 show the proportion estimates for each strategy. As the empirical results and sample estimates suggested, the probability of a first bus strategy decreases as trip length increases. A few anomalies are observed. In Market 1, only 36.4% of passengers with trips of 45 minutes or longer are estimated to employ a favorite bus strategy. Given the time savings gained from taking Route 607 for this length of trip, this is surprising. However, only two OD pairs in Market 1 are 45 minutes or longer and only 46 people traveled between these OD pairs in the AM peak. This small sample size introduces a degree of uncertainty to the strategy estimates for this group.

The other interesting pattern is the presence of some preference for Route 207 in Market 2. For trips between 20 and 30 minutes long, 12.4% of passengers are estimated to wait specifically for the Route 207 buses. This sample includes passengers boarding at two stops: Ealing Hospital and Leeland Road. The Route 607 loads at these stops in the AM peak are quite high. The median AM peak weekday loads for this two-week period were 74 people and 79 people, respectively, and the highest ten percent of loads were greater than 94 people. The preference for Route 207 may be a sign of passengers avoiding crowded Route 607 in favor of Route 207 buses which have median loads of 30 and 43 people, respectively and 90th percentile loads of 53 people at Ealing Hospital and 74 people at Leeland Road. The next section will include more analysis of the effects of crowding on behavior.

**Table 4.17:** Uxbridge Corridor Market 1 Strategies by Trip Length

| Route 607 Travel Time | First Bus | Favorite Bus: Route 427 | Favorite Bus: Route 607 |
|---|---|---|---|
| Less than 10 minutes | 0.750 | 0.037 | 0.213 |
| 10 to 20 minutes | 0.652 | 0.000 | 0.348 |
| 20 to 30 minutes | 0.369 | 0.000 | 0.631 |
| 30 to 45 minutes | 0.218 | 0.000 | 0.782 |
| 45 minutes or more | 0.636 | 0.000 | 0.364 |

**Table 4.18:** Uxbridge Corridor Market 2 Strategies by Trip Length

| Route 607 Travel Time | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 |
|---|---|---|---|
| Less than 10 minutes | 0.715 | 0.076 | 0.209 |
| 10 to 20 minutes | 0.743 | 0.066 | 0.191 |
| 20 to 30 minutes | 0.251 | 0.124 | 0.626 |
| 30 to 45 minutes | 0.298 | 0.013 | 0.689 |
| 45 minutes or more | 0.166 | 0.001 | 0.833 |

Table 4.19: Uxbridge Corridor Market 3 Strategies by Trip Length

| Route 607 Travel Time | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 427 | Favorite Bus: Route 607 |
|---|---|---|---|---|
| Less than 10 minutes | 0.921 | 0.009 | 0.000 | 0.07 |
| 10 to 20 minutes | 0.779 | 0.000 | 0.000 | 0.218 |
| 20 to 30 minutes | 0.497 | 0.000 | 0.005 | 0.498 |

**Crowding**

This set of analyses considers the passenger load on the bus when it departs the stop the passenger boarded at. If buses of one route are consistently more crowded, passengers who are sensitive to crowding may avoid that route.

Figure 4-7 shows the median AM peak loads on each route at each stop served by Route 607, the limited stop route. The median loads on routes 207 and 427 remain below 50 passengers per bus. The 90th percentile loads for the local stops are 75 passengers or fewer with the exception of Route 207 at the Adelaide Grove stop, which has a 90th percentile load of 97 passengers. Adelaide Grove is near the end of the route and several parallel routes run from Adelaide Grove to the end of the corridor. Therefore all boardings at Adelaide Grove have already been excluded from the analysis. It is therefore fair to state that crowding and capacity issues are not significant for the local routes at any of the shared stops included in the analysis. The Route 207 buses have a seated capacity of 63 people with space for an additional 24 standing passengers. Route 427 vehicles have 67 seats and space for 26 standees. Route 607 buses have a similar capacity. They have 63 seats and space for about 25 standing passengers according to vehicle capacity estimates. The data, however, indicates that loads exceed this 88-person capacity in the inbound AM peak. At the stops from Southall Police Station to Leeland Road, median loads are above 70 people and 90th percentile loads range from 94 to 97 people, indicating that at least 10% of Route 607 buses at these stops are very full.

The boarding stops for Market 1 are not especially crowded. The final stop before Route 207 begins, the Grapes, is more crowded than the previous stops, with a median Route 607 load of 47 people and 90th percentile load of 68. Boardings at the Grapes were analyzed separately from the rest of Market 1. However, no significant difference in behavior was found, indicating that passenger behavior in the presence of moderate loads is no different from their behavior when vehicle loads are low.

In markets 2 and 3, most passengers board at crowded stops, but some passengers board at stops that have only moderate loads. This allows for comparison of the behavior of passengers boarding at crowded stops with that of passengers boarding at less crowded stops.

For Market 2, the impact of crowding on behavior for shorter trips and longer trips is analyzed separately. Shorter trips were defined as trips lasting from 6 to 20 minutes on Route 607. This range of trip lengths was used because passengers took trips of these lengths starting from both crowded and uncrowded stops. The sample for the analysis of the behavior of people boarding at stops with crowded buses includes boardings at Bromyard Avenue and Leeland Road. Median loads at Bromyard Avenue are only 53 passengers, but

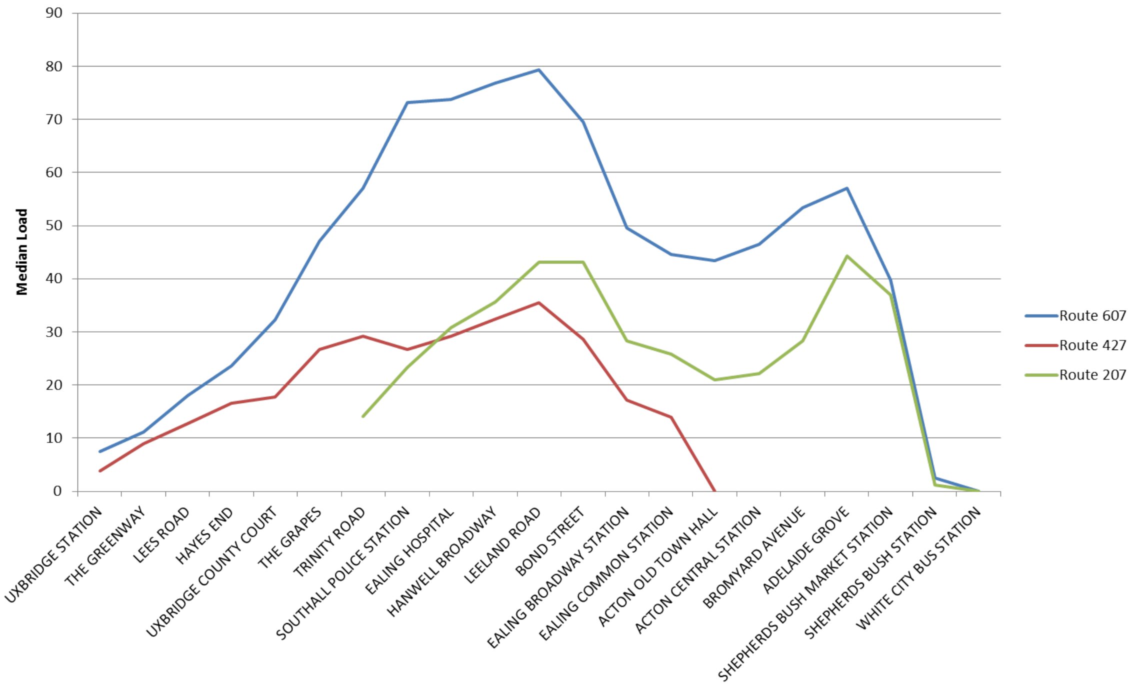



**Figure 4-7:** Uxbridge Corridor Inbound AM Peak Median Loads

90th percentile loads are high, 94 passengers. These passengers in the crowded group took trips averaging 10.2 minutes. The crowded group is compared to passengers who took trips of similar lengths, with a range of 6 to 18 minutes and an average of 12.7 minutes, boarding at uncrowded stops. The uncrowded group consists exclusively of passengers boarding at Acton Central Station, because this was the only stop in Market 2 with uncrowded buses that had OD pairs with short travel times.

Table 4.20 shows that some passengers boarding at the crowded stops preferred to wait for Route 207, the slower but uncrowded local route. While nobody boarding at the uncrowded stop waited specifically for a Route 207 bus, 11.6% of passengers boarding at crowded stops are estimated to wait specifically for a Route 207 bus. This supports the hypothesis that when Route 607 buses are crowded, passengers elect to wait specifically for Route 207 buses in order to avoid crowding. One would expect the preference for Route 607 to be greater at the uncrowded stop because it provides faster service without the costs to comfort of a crowded bus. However, the opposite is observed. This may have to do with other factors associated with the boarding stops or with the distribution of trip lengths for the two samples. In addition, despite the attempt to control for trip length, in terms of minutes on Route 607, there may be variation in the travel time savings. Depending on traffic, the difference between limited stop bus speeds and local bus speeds can vary. If traffic is heavy, the savings may be small, but on portions of the route with lighter traffic, the savings even on a short trip can be significant.

The longer trips analyzed in Market 2 last between 35 and 47 minutes on Route 607. The crowded sample consists of passengers boarding at Southall Police Station, Leeland Road, and Ealing Hospital and traveling on average for 41.9 minutes. These passengers' behavior is compared to passengers boarding at Trinity Road, at which point Route 607 buses are much

**Table 4.20:** Market 2 Strategies at Crowded and Uncrowded Stops (Short Trips)

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 |
|---|---|---|---|
| Crowded | 0.670 | 0.116 | 0.214 |
| Not Crowded | 0.836 | 0.000 | 0.164 |

less crowded, with median loads of 57 passengers and 90th percentile loads of 79 passengers. The passengers traveling from Trinity Road took trips averaging 42.8 minutes. Table 4.21 shows that for this longer distance, passengers are more willing to endure the crowded Route 607 buses, likely because of the significant time savings. Only 1.1% of passengers at the crowded stop are estimated to wait specifically for a Route 207 bus to arrive. The preference for Route 607 is less strong at the crowded stops than at the uncrowded stops. This could be an indication that passengers view Route 607 less favorably when it is significantly more crowded than the alternative, local route. They opt against waiting for it specifically, but if it is the first bus to come along, they are willing to take it.

**Table 4.21:** Market 2 Strategies at Crowded and Uncrowded Stops (Long Trips)

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 |
|---|---|---|---|
| Crowded | 0.253 | 0.011 | 0.736 |
| Not Crowded | 0.173 | 0.000 | 0.827 |

Because there are no long trips possible within Market 3, only one set of trip lengths is analyzed, with trips of 9 to 24 minutes. Removing the shortest and longest trips from moderate and crowded stops attempts to control for variation that should be attributed to trip length rather than crowding. The crowded sample includes passengers boarding at Southall Police Station, Leeland Road, and Ealing Hospital, and making trips that average 17.5 minutes on Route 607. These passengers' behavior is compared to passengers boarding at Trinity Road and making trips that average 19.4 minutes on Route 607. Table 4.22 shows estimates for the strategies for these two groups. At crowded stops, only 24.4% of passengers wait for Route 607 buses compared to 39.6% of passengers at the less crowded stop. As noted for Market 2, this likely reflects that fact that the cost of crowding outweighs the perceived time savings for taking Route 607 for some passengers. Unlike in market 2, one does not observe a preference for the local routes at the crowded stop. However, this may be a function of the model structure. The model only provides estimates for passengers who wait for a specific route. In fact, crowding averse people are likely willing to take either of the local routes. This strategy is not built into the model and because local buses will often be preceded by an arrival of a different local bus, many of the passengers with this strategy are likely to be miscategorized as having a first bus strategy by the model.

In summary, crowding leads some users to prefer the local routes, particularly for shorter trips where the time savings that result from waiting for Route 607 are not substantial. For both shorter and longer trips, passengers boarding at more-crowded stops tend to have less of a preference for Route 607 buses than passengers taking comparable trips from less-crowded stops. This indicates that while many passengers perceive value in the time savings

**Table 4.22:** Market 3 Strategies at Crowded and Uncrowded Stops

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 427 | Favorite Bus: Route 607 |
|---|---|---|---|---|
| Crowded | 0.749 | 0.000 | 0.006 | 0.244 |
| Not Crowded | 0.598 | 0.000 | 0.006 | 0.396 |

from taking Route 607, for some passengers this value is outweighed by their aversion to riding buses that are significantly more crowded than the local buses.

### Frequency of Corridor Use

The next set of analyses consider how the behavior of passengers who use the corridor frequently (passengers with six or more inbound trips in the ten days analyzed) differs from passengers who have just one trip in the two-week period, designated as infrequent users. Samples from each market are considered, controlling both for trip length and crowding. Infrequent users may have less knowledge of the in-vehicle time savings provided by Route 607 or may not have full knowledge of which stops it serves. In addition, frequent users are likely to have different trip purposes than infrequent users of the corridor. Frequent users who are commuting to work or school are likely to be more time sensitive than infrequent users on shopping or leisure trips. Those on shopping or leisure trips may be more sensitive to crowding. Frequent users are expected to have better knowledge of the corridor. They may be more aware of the possible time savings resulting from taking Route 607 and of the stops that it serves. This would make them more likely to take Route 607. In addition with the correlation to trip purpose, infrequent users of the corridor may have different demographic characteristics than frequent users. While frequent users may include younger individuals on school and work trips, infrequent users are more likely to include older adults taking occasional trips. These older adults may be more sensitive to crowding and less time sensitive than younger people.

For Market 1, trips that take 10 to 30 minutes on Route 607 are considered. Crowding was deemed insignificant in Market 1, where loads on Route 607 vary from low to moderate. Therefore, all boarding stops are considered. Table 4.23 shows that frequent users of the corridor are more likely to use a favorite bus strategy, waiting specifically for Route 607. 55.3% of frequent users were estimated to wait for Route 607 compared to just 39.6% of infrequent users. This suggests that frequent users are either more aware or place greater value on the perceived time savings of taking Route 607 buses.

**Table 4.23:** Market 1 Strategies for Frequent and Infrequent Users

| | First Bus | Favorite Bus: Route 427 | Favorite Bus: Route 607 |
|---|---|---|---|
| Infrequent | 0.595 | 0.009 | 0.396 |
| Frequent | 0.447 | 0.000 | 0.553 |

For Market 2, short trips of less than 20 minutes are considered. For these trips, a significant difference was observed in the behavior of passengers boarding at crowded stops from those boarding at a less crowded stop. Specifically, the passengers boarding at crowded stops showed some preference for the local route, Route 207. Therefore, the frequency analysis is applied first to the crowded stops and then to the less crowded stop. At the crowded stops, infrequent users showed a strong preference for Route 207, with 21.9% of passengers waiting specifically for a Route 207 bus. In contrast, only 8.9% of frequent users wait for a Route 207 bus. This is indicative of crowding being a greater driver of behavior for infrequent users than frequent users. The frequent users were more likely to have a favorite bus strategy, preferring Route 607 than the infrequent users. 21.4% of frequent users compared to only 16.6% of infrequent users waited for Route 607. This indicates that frequent users are either more time sensitive or have more awareness of limited stop service than infrequent users (See Table 4.24).

**Table 4.24:** Market 2 Strategies for Frequent and Infrequent Users (Crowded Stops, Short Trips)

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 |
|---|---|---|---|
| Infrequent | 0.614 | 0.219 | 0.166 |
| Frequent | 0.697 | 0.089 | 0.214 |

At the uncrowded stop, passengers taking trips shorter than 20 minutes long showed no preference for the local route. Frequent users of the corridor were somewhat more likely to wait for the limited stop route. 16.7% of frequent users compared to 12.7% of infrequent users were estimated to wait specifically for Route 607 buses. These results are summarized in Table 4.25.

**Table 4.25:** Market 2 Strategies for Frequent and Infrequent Users (Uncrowded Stops, Short Trips)

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 |
|---|---|---|---|
| Infrequent | 0.873 | 0.000 | 0.127 |
| Frequent | 0.833 | 0.000 | 0.167 |

Longer trips in Market 2 were also analyzed. Because the sample size for long trips departing from an uncrowded stop was small, only those trips beginning at crowded stops were analyzed. Trips of 35 to 47 minutes on Route 607 were assessed. Similar to previous results, frequent users were found to be more likely than infrequent users to wait for limited stop service, Route 607. For these longer trips, the time savings are more significant than for the shorter trips analyzed in tables 4.24 and 4.25. In fact, for those shorter trips of less than 20 minutes, the time savings for Route 607 are marginal, particularly given that Route 607 buses have longer headways than Route 207 buses. If the primary driver of infrequent users' behavior is lack of knowledge, one might expect the difference in behavior between infrequent and frequent users to be greater for longer trips than for shorter trips. That is, for shorter trips, knowledge is not especially helpful because all strategies are likely to result in similar travel times. For longer trips, people with knowledge of the corridor are aware of the significant time savings of using Route 607, while passengers without this knowledge would not be. In fact, the difference in behavior for infrequent and frequent users is similar for shorter and longer trips. For longer trips, 74.1% of frequent users wait for Route 607 while 69.7% of infrequent users wait for Route 607, as summarized in Table 4.26. This suggests that most infrequent users are knowledgeable of the corridor and are motivated by having a stronger distaste for crowding than frequent users. For longer trips, the time savings outweigh the benefit of reduced crowding for both infrequent and frequent users, but this effect is slightly stronger for frequent users.

**Table 4.26:** Market 2 Strategies for Frequent and Infrequent Users (Crowded Stops, Long Trips)

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 |
|---|---|---|---|
| Infrequent | 0.303 | 0.000 | 0.697 |
| Frequent | 0.244 | 0.015 | 0.741 |

For Market 3, similar patterns are observed. Trips of 9 to 24 minutes on Route 607 were analyzed, with boardings at crowded and uncrowded stops assigned to separate groups. At the crowded stops, infrequent users showed a small preference for Route 427, with 3.4% of passengers waiting for this local bus route. This is a sign of avoidance of crowded vehicles by these users. The frequent users at these crowded stops were significantly more likely to wait for Route 607 buses, with 25% of frequent users waiting for limited stop service compared to just 14.8% of infrequent users. These results are summarized in Table 4.27.

**Table 4.27:** Market 3 Strategies for Frequent and Infrequent Users (Crowded Stops)

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 427 | Favorite Bus: Route 607 |
|---|---|---|---|---|
| Infrequent | 0.818 | 0.000 | 0.034 | 0.148 |
| Frequent | 0.746 | 0.000 | 0.004 | 0.25 |

For boardings at the uncrowded stop, behavior patterns are similar, with a stronger overall preference for Route 607 for both groups. 28.8% of infrequent users of the corridor prefer Route 607 and 43% of frequent users wait for Route 607. 2.4% of infrequent users prefer Route 427 even though Route 607 buses are not crowded at this boarding stop. This may be due to anticipation of crowding at subsequent stops or may be a sign of lack of full knowledge of the routes that serve their destinations. Table 4.28 shows these results.

**Table 4.28:** Market 3 Strategies for Frequent and Infrequent Users (Uncrowded Stops)

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 427 | Favorite Bus: Route 607 |
|---|---|---|---|---|
| Infrequent | 0.688 | 0.000 | 0.024 | 0.288 |
| Frequent | 0.569 | 0.000 | 0.000 | 0.430 |

In summary, frequent users behave differently from infrequent users. Frequent users seem to place more value on time savings and less value on avoiding crowded buses than infrequent users. This may be correlated to the different trip purposes and demographics of frequent users compared to infrequent users.

It is possible that even within the restricted trip length ranges used, frequent users tend to take longer trips than infrequent users, accounting for some of the behavioral differences observed. To check this, average trip lengths are computed for each group for each of the samples analyzed. Table 4.29, which shows average trip lengths in terms of Route 607 running time in minutes, reveals that this was not a significant problem. In most cases, the average trip lengths for frequent and infrequent users in the samples analyzed were comparable. The largest difference is in the the trips analyzed in Market 3 that began at an uncrowded stop. From this stop, frequent users took trips that averaged 19.6 minutes while infrequent users took trips of 17.4 minutes. This confirms that the differences in behavior of frequent and infrequent users are not due to trip length, but rather are likely due to differences in sensitivity to time savings and crowding, and possible differences in knowledge between the two user types.

**Table 4.29:** Average Route 607 Trip Lengths in Frequency Analysis

| | Infrequent Users | Frequent Users |
|---|---|---|
| Market 1, Trips of 10 to 30 minutes | 20.5 | 21.2 |
| Market 2, Trips of less than 20 minutes, Crowded | 9.9 | 9.9 |
| Market 2, Trips of less than 20 minutes, Uncrowded | 12.7 | 12.7 |
| Market 2, Trips of 35 to 47 minutes, Crowded | 42.2 | 41.8 |
| Market 3, Trips of 9 to 24 minutes, Crowded | 17.1 | 17.8 |
| Market 3, Trips of 9 to 24 minutes, Uncrowded | 17.4 | 19.6 |

### Countdown Information

A final set of analyses use the probabilistic model to determine if passenger behavior varies according to whether or not a countdown sign is available at the stop. The countdown signs show the number of minutes until arriving buses will reach the stop. This can help people decide whether or not to use a favorite bus strategy. In general, studies show that this information also makes waiting time less onerous. This could make passengers more willing to endure the slightly longer waits for Route 607 buses. Hanwell Broadway, a stop between Ealing Hospital and Leeland Road has a similarly high level of crowding to these neighboring stops, but has no countdown sign at the stop. This allows for comparison of the behavior of passengers boarding at Hanwell Broadway to that of passengers boarding at Ealing Hospital and Leeland Road, which both have countdown signs. Most of the passengers are in Market 2, selecting between routes 207 and 607. Market 2 passengers boarding at Hanwell Broadway take trips ranging from 22 to 42 minutes, with an average of 32.3 minutes. Market 2 passengers boarding at Ealing Hospital and Leeland Road take trips averaging 31.4 minutes and ranging from 19 to 44 minutes. Therefore these samples are comparable not only in terms of crowding, but also in terms in trip length.

Passengers boarding at Hanwell Broadway, the stop without countdown information were more likely to board the first bus, with 51.9% of passengers estimated to have this strategy, compared to 39.6% of passengers at the neighboring stops that have countdown signs. The passengers at the stops with countdown information are more likely to wait for Route 607 buses, as Table 4.30 shows. This supports the hypothesis that passengers are more willing to wait for Route 607 buses when they know when it will arrive. Passengers boarding at the stop without countdown information also show a slightly greater preference for Route 207, 5.8% instead of 2.5%. The reason for this difference is unclear and may be unrelated to the presence of countdown information.

**Table 4.30:** Strategies at Stops With and Without Countdown Signs

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 |
|---|---|---|---|
| Countdown | 0.396 | 0.025 | 0.579 |
| No Countdown | 0.519 | 0.058 | 0.423 |

## 4.6 Probabilistic Model Conclusions

The probabilistic model can be used to look in greater depth at passenger strategies controlling for features of the routes, stops, or of the passengers. In the Beulah Corridor, different behavior was observed in the inbound and outbound directions of the AM peak. Passengers in the inbound direction were less likely to have first bus strategies, probably due to more crowding on inbound buses than on outbound buses. On the Uxbridge Corridor, trip length was the most significant factor influencing behavior, with passengers making longer trips more likely to prefer Route 607, the limited stop service route. Passengers on the Uxbridge Corridor also showed sensitivity to crowding. For shorter trips, crowded Route 607 buses seem to drive some passengers to wait for less-crowded local buses. In general, high passenger loads on Route 607 buses reduced the preference for these buses at these high-load stops. The sensitivity to crowded buses appeared to be greater for infrequent users of the corridor than for frequent users. At the same time, frequent users show more of a desire for the time savings gained by taking Route 607 bus. Passengers who boarded at stops with countdown signs providing information about future bus arrivals were more likely to wait for a Route 607 bus and less likely to simply board the first bus.

The probabilistic model is limited to estimating the proportion of passengers with favorite bus strategies (passengers wait for a bus of a specific route no matter what) and first bus strategies (passengers board the first bus that serves their destination, regardless of upcoming arrivals of other routes). In fact, passengers are likely to have flexible strategies.

The model also cannot distinguish passengers who do not board the first bus that serves their destination because a bus passes them that is already at capacity from passengers who do not board the first bus that serves their destination because they prefer a different bus route. However, the probabilistic model is a useful tool for estimating passenger strategies based on automatically collected data. It proved to adequately predict the actual ridership patterns, when applied to the samples on both corridors.

## 4.7 Panel Analysis Methodology

The panel analysis examines the behavior over time of individuals who take repeated trips on the corridor. If passengers board the same bus route for repeated trips, this may indicate a preference for that bus route. However, this could also be the result of coincidence - the bus route happened to be the first bus to arrive each time the individual took a trip. The probability of this chance occurrence can be estimated as the product of probabilities that a given bus route arrives first for each of an individual's trips, as in Equation 4.3. If the proportion of passengers taking all of their trips on one route is substantially greater than this chance probability, this is an indication of passengers favoring one route over others.

$$\text{Probability route } i \text{ arrives first for all } t \text{ trips } = \left(\frac{V_i}{\sum_{i=1}^{I} V_i}\right)^t \tag{4.3}$$

Where $V_i$ is the number of vehicle trips per day on route $i$, and the individual is selecting between a set of $I$ routes.

One can also calculate an expected distribution of the proportion of trips on a given route, assuming a fixed proportion of bus arrivals are of that route, and using the binomial distribution to calculate the probability of a given number of trips being taken on that route (See Equation 4.4). This expected distribution can be compared to the actual distribution of the percent of trips on a given route by passengers with a specified number of trips.

$$\text{Probability route } i \text{ arrives first } x \text{ times out of } t \text{ trips} = \binom{t}{x} p^x (1-p)^{t-x} \tag{4.4}$$

Where $p$ is the proportion of bus arrivals of route $i$

Panel analysis can also be used to determine the degree to which passengers vary their boarding and alighting stop from trip to trip. On both corridors, some stops are not shared between the routes, but rather are located a block or more away from one another. Passengers' flexibility of stop choice is assessed in a similar way to their route choice flexibility. On the Beulah Corridor, analysis is conducted of passengers who board at a geographically offset stop. An expected binomial distribution is constructed, assuming passengers have no preferences between boarding stops. This is compared to the actual distribution of passengers' proportions of trips from each boarding stop. The same analysis is conducting for passengers who alight at a geographically offset stop.

On the Uxbridge Corridor, some passengers face a trade-off between walking farther to a stop served by Route 607 buses or going to a closer stop served only by local buses. Similarly, depending on which bus they board, they may vary their alighting stop depending on which stops the route they boarded serves. To study this variation, OD pairs served by Route 607 buses are grouped with boardings and alightings at neighboring local-only stops. Passengers with multiple trips on these sets of boarding and alighting stops form a panel and the extent to which they use the same OD pair for all their trips is assessed.

## 4.8 Panel Analysis Results

### 4.8.1 Beulah Corridor

In the Beulah Corridor, the empirical and probabilistic analysis indicates that most passengers board the first bus that serves their destination, and the panel analysis confirms this finding. Table 4.31 groups individuals by the number of trips they took on the Beulah Corridor over the ten-day period and compares the proportion of passengers who took all their trips on a given route to the probability of this occurring randomly. Values in bold indicate a difference of more than 2% between the random probability and the proportion observed. There are seven cases where the proportion of passengers taking all their trips on one route is more than 2% higher than the expected proportion. In three of these cases, the sample size is smaller than 100, which may account for the deviation. Most importantly, there are no instances of large difference between the probability of this occurring randomly and the actual proportion. The greatest difference is for passengers who took five trips on the corridor. 12.6% of these passengers took all their trips on Route 468. The estimated probability of this occurring randomly is just 9.5%, or 3.1% less than the actual. This deviation may be due to the fact that the probability of random occurrence is a rough estimate. Using the total vehicle trips per day for each route to estimate the probability that a given arrival is of a given route does not account for variation by stop or time of day, particularly given that arrivals of buses at different stops are not coordinated.

**Table 4.31:** Beulah Corridor Panel Analysis of Passengers with All Trips on One Route

| Number of Trips Taken | Route 196 For All Trips | Probability of Random Occurrence | Route 468 For All Trips | Probability of Random Occurrence | Sample Size |
|---|---|---|---|---|---|
| 14-32 | 0.0% | 0.0% | 0.0% | 0.0% | 125 |
| 13 | 0.0% | 0.0% | **3.0%** | 0.2% | 33 |
| 12 | 0.0% | 0.0% | 0.0% | 0.4% | 43 |
| 11 | 0.0% | 0.0% | 0.0% | 0.6% | 69 |
| 10 | 0.0% | 0.0% | **2.8%** | 0.9% | 71 |
| 9 | 1.1% | 0.0% | **4.4%** | 1.5% | 91 |
| 8 | 0.0% | 0.0% | 3.6% | 2.3% | 111 |
| 7 | 0.0% | 0.1% | 3.6% | 3.7% | 138 |
| 6 | 0.0% | 0.3% | **8.6%** | 6.0% | 198 |
| 5 | 2.4% | 0.7% | **12.6%** | 9.5% | 253 |
| 4 | 3.6% | 2.0% | 16.5% | 15.3% | 389 |
| 3 | **7.3%** | 5.3% | 22.7% | 24.4% | 587 |
| 2 | **16.9%** | 14.1% | 37.9% | 39.1% | 1369 |

To further test the behavior of the panel, the binomial distribution is used to plot an expected distribution for individuals with eight total trips on the corridor. Passengers with eight trips were selected for further analysis because this was a sufficient number of trips to construct a distribution, and also has a substantial number of passengers (111 people took eight trips in the ten days analyzed). Figure 4-8 shows that the actual distribution of the number of trips these individuals took on Route 468 is a very close match to the expected distribution under the assumption that passengers board the first bus for all of their trips. This confirms the dominance of the first bus strategy on the corridor.

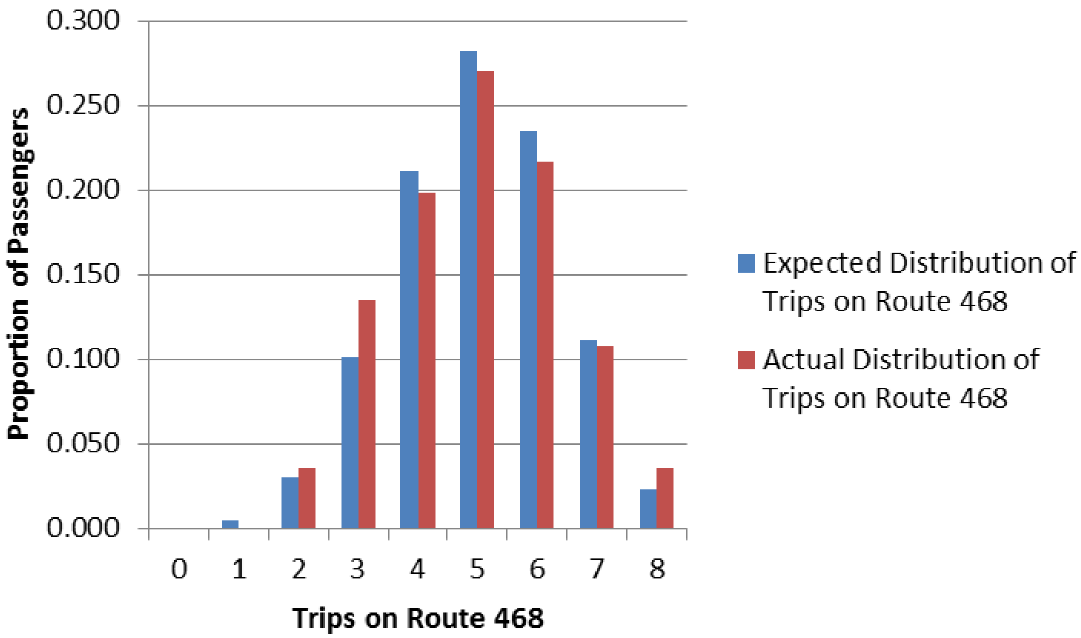



**Figure 4-8:** Beulah Corridor Panel Analysis

Passengers' flexibility of boarding stop selection is analyzed in a similar way. Passengers who board at the Norwood/ Robson Road stop traveling inbound must select between the stop served by Route 196 and the stop served by Route 468. One might expect that they would go to the stop closer to their house or whatever location they are coming from. One might also expect that passengers would prefer the stop served by Route 468, because it has more frequent service. If passengers have a strong preference for one stop, it is expected that a high percentage of their trips originate at that stop. Considering all passengers who took three or more trips from one of the two Norwood/ Robson Road stops, there does seem to be some favoritism for each stop. Figure 4-9 shows the distribution of the percent of trips individuals' took from the Route 468 stop. The distribution has fat tails of passengers who took all their trips from one stop. However, many passengers also show flexibility in their boarding stop, indicating that they do not favor one boarding stop over the other.

Passengers who alight at a location where the Route 196 and Route 468 stops are offset also face a choice. They may prefer to wait for a specific bus route so that they can alight at their preferred stop. However, if they have no preference between the two alighting stops, they will board the first bus that arrives. To consider passengers alighting stop flexibility, passengers who took five or more trips in which they alighted at one of the Norwood/ Robson

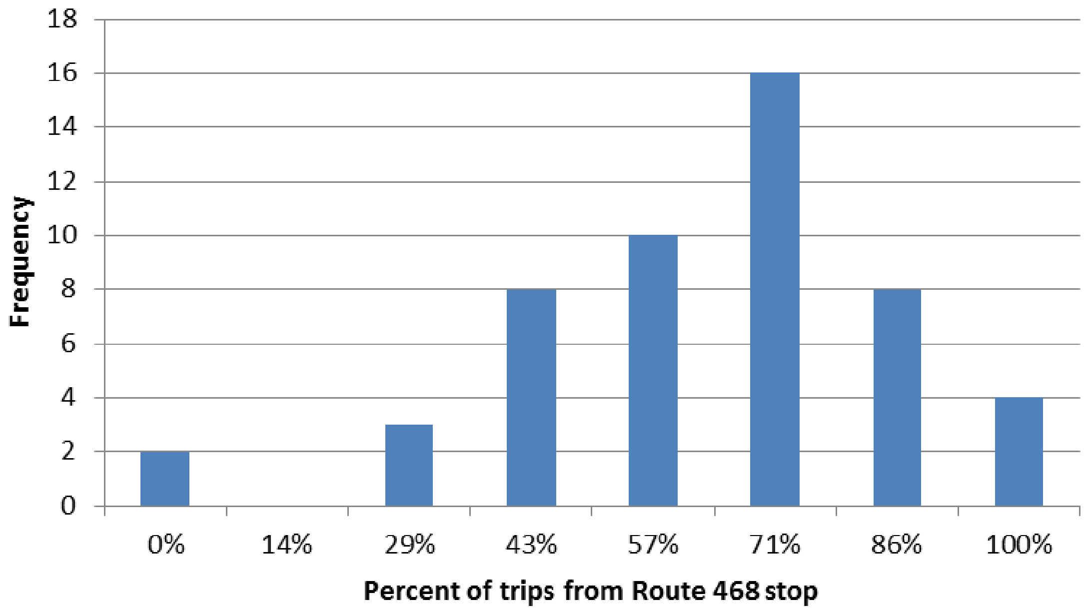



**Figure 4-9:** Distribution of Selection between Offset Boarding Stops

Road stops are analyzed. If these passengers had no stop preference and simply boarded the first bus, one would expect the probability that they alight at each stop is proportional to the service frequency of each route. Using this proportion, a binomial distribution can be constructed assuming passengers have seven trips in total (this was the average number of total trips for the sample). Figure 4-10 shows this expected distribution compared to the actual frequency with which passengers selected Route 468. Compared to the expected distribution, the actual distribution shows more people opting to take 70% or more of their trips on Route 468. There are also more people than expected who take all of their trips on Route 196. This implies that passengers do have preferences for alighting stops, probably preferring the one closest to their destination, that influence their route choice.

### 4.8.2 Uxbridge Corridor

To control for the many factors that influence behavior on the Uxbridge Corridor, the panel analysis focuses on passengers traveling on a specific OD pair. The analysis considers passengers who travel inbound from Southall Police Station to Ealing Common Station and outbound from Ealing Common Station to Southall Police Station. These passengers can select between all three routes: 207, 427, and 607. Table 4.32 shows that a much higher proportion of passengers take all their trips on Route 607 than one would expect to occur randomly, if everyone boarded the first bus. This confirms the pattern put forth by the empirical and probabilistic analyses, which revealed a preference for Route 607, particularly for longer trips.

To confirm this preference, individuals with four trips are analyzed in more detail. Using the binomial distribution, the expected proportion of individuals who took a given number of these trips on Route 607 is calculated, assuming these passengers boarded the first bus

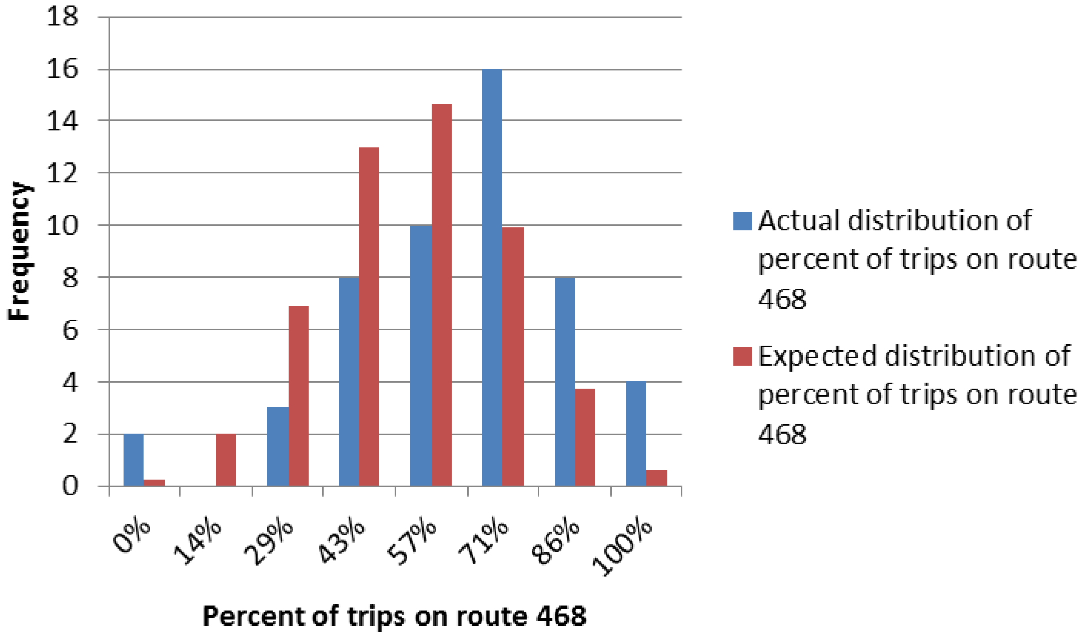



**Figure 4-10:** Distribution of Selection between Offset Destination Stops

serving their destination. This is compared to the distribution of the actual number of trips these individuals took on Route 607 in Figure 4-11. The two distributions are very different, confirming that many of these individuals are likely not using a first bus strategy.

The extent to which individuals vary the stop at which they board and alight in the Uxbridge Corridor can also be studied using a panel. This analysis is conducted for each direction separately. In the inbound direction, boardings at Southalll Police Station, as well as the local stops preceding and following this stop are included. All passengers with at least three inbound trips that begin at one of these three stops and end at either Ealing Common Station or the local stops before and after it are included in the analysis. 127 people fit in this group for the ten weekdays analyzed. With three possible boarding stops and three possible alighting stops, there are nine potential OD pairs in the inbound direction. 60% of passen-

**Table 4.32:** Uxbridge Corridor Panel Analysis of Passengers with All Trips on One Route

| Number of Trips Taken | Local Routes for All | Probability of Random Occurrence | Route 607 For All Trips | Probability of Random Occurrence | Sample Size |
|---|---|---|---|---|---|
| 8 to 19 | 0.0% | 0.0% | 0.0% | 0.0% | 43 |
| 7 | 0.0% | 16.3% | **12.5%** | 0.0% | 8 |
| 6 | 0.0% | 21.1% | **28.6%** | 0.0% | 7 |
| 5 | 6.7% | 27.3% | **33.3%** | 0.1% | 15 |
| 4 | 4.5% | 35.4% | **50.0%** | 0.3% | 22 |
| 3 | 9.4% | 45.9% | **34.0%** | 1.2% | 53 |
| 2 | 10.4% | 59.5% | **63.5%** | 5.2% | 115 |

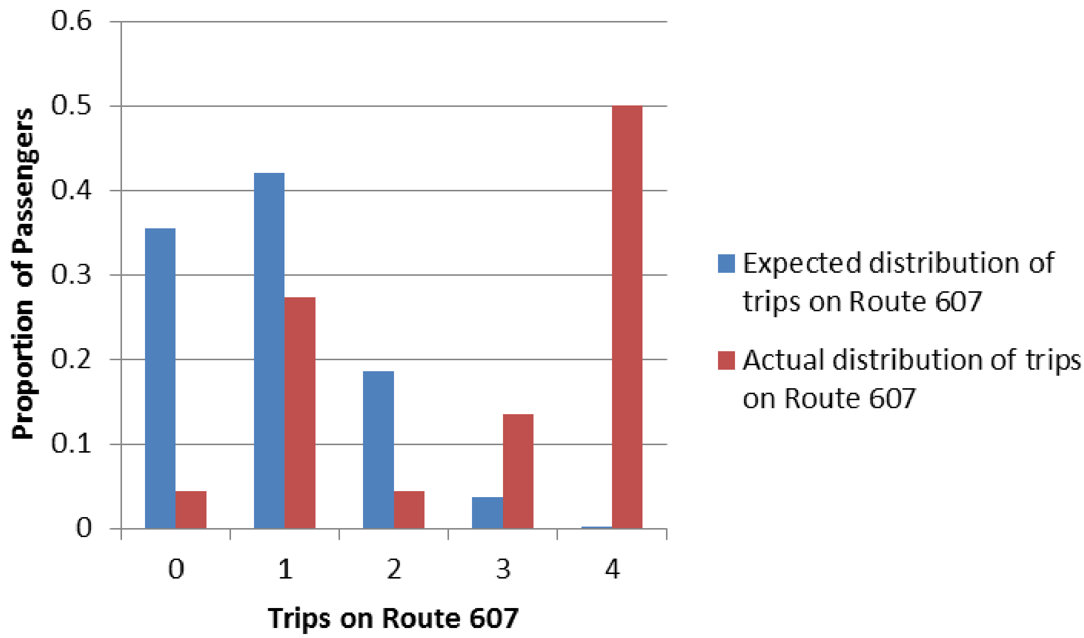



**Figure 4-11:** Uxbridge Corridor Panel Analysis

gers took all of their trips on the same OD pair. This means that almost 40% of passengers vary their boarding and/or alighting stops in some way. This indicates that passengers demonstrate some flexibility in selecting their boarding and alighting stops.

Similar analysis was performed in the outbound direction. 139 people took three or more trips over the ten weekdays analyzed that began at Ealing Common Station or the neighboring local stops and ended at Southall Police Station or the stops before and after it. Only 15% of these passengers made all their trips on the same OD pair. That is, almost 85% of passengers varied either their boarding or alighting stop or both. This means that for this specific OD pair in the outbound direction, passengers are particularly flexible when selecting their boarding and alighting stops.

## 4.9 Panel Analysis Conclusions

The panel analysis offers a look at the variation of individual's behavior in terms of both route choice and stop choice. In terms of route choice, the panel analysis reflects the ambivalence to the different routes on the Beulah Corridor and the preference for Route 607 on the Uxbridge Corridor. The analysis of stop variation shows that passengers have some flexibility, but that some passengers prefer specific stops on both corridors.

All three methods presented in this chapter infer information about passenger strategies based on passenger boardings and bus arrival information only. The web-based survey, discussed in the next chapter, collects information about passenger strategies directly and also gathers data on many other explanatory factors that cannot be observed in automatically collected data. This serves to augment the analysis presented here.

# Chapter 5

# Design, Representativeness, and Validity of the Web-Based Survey

While information about passenger behavior and route choice strategies can be inferred from automated data sources, the most direct way to determine passengers' strategies is to ask them in a survey. Surveys can also collect other information about the individuals including their attitudes and demographics, and additional information about the trip such as the trip purpose. Online (internet) surveys represent a relatively new way to collect this information. This chapter begins with a brief review of the research on surveys in transportation, and discusses the advantages and disadvantages of using an online survey. This is followed with a description of the survey design used in this research and analysis of the representativeness and validity of the survey data collected.

## 5.1 Web-Based Surveys

Surveys can take many forms including onboard surveys, more extended face-to-face interviews, mail-out surveys, and telephone surveys. Onboard surveys must be short so that passengers can easily complete them onboard the bus. In London, the Bus Passenger Origin and Destination Survey (BODS) is conducted on each bus route every five to seven years. The survey is very brief, focusing mainly on recording the individual's boarding and alighting stop. Each route is surveyed on one day. The percentage of trips that are surveyed depends on the route. For high volume routes it is as low as 60% (Wang et al., 2011). For more detailed information, TfL conducts the London Travel Demand Survey (LTDS) in which they try to reach 8,000 households each year (Transport for London, 2009). A web-based survey targeted at corridor users can fill the gap by collecting more information than an onboard survey is able to, but still reaching a large number of people. Web-based surveys appear to be a better option than a mail-out survey because responses can be collected more quickly and at lower cost. In addition, Cobanoglu et al. (2001) found the response rate for web-based surveys to be significantly higher than for mail-based surveys with no difference in the quality of the data. One issue with web-based surveys, raised by Cobanoglu et al.

is the high possibility of coverage errors. That is, it is difficult for a web-based survey to reach a representative sample of the population under consideration.

Another potential issue with web-based surveys is that respondents may not remember the details of a recent trip they took. This issue arises in travel diary surveys as well, but is typically not a problem for onboard surveys. Stopher and Shen (2011) note that respondents may confuse recent trips with one another. In many cases, respondents fail to report trips either because they forget or think that they are not important (Stopher et al., 2007). Most of the trips that respondents fail to report are short trips of less than ten minutes (Stopher et al., 2007).

In web-based surveys, there is no flexibility of interaction with an interviewer to help clarify questions. Therefore, the questions and instructions must be clear. Some errors in survey data stem from respondents misunderstanding questions. Stopher and Shen note that, in particular, some respondents fail to understand what is meant by a trip. Web-based and mail surveys are also susceptible to incomplete surveys. In some cases, passengers do not wish to report sensitive information (Stopher and Shen, 2011). In other cases, questions are left blank due to survey fatigue (Stopher et al., 2007). Face-to-face surveys do not have these issues, but can have other problems with bias introduced by the interviewer. Respondents may be concerned with what the interviewer thinks, leading to social desirability bias (Eboli and Mazzulla, 2009).

In summary, a web-based survey has a distinct advantage over an onboard survey because it can be longer, asking more questions, and gathering more information. Compared to in-depth face-to-face interviews, online surveys can reach a much wider audience at a tiny fraction of the cost. This means that web-based surveys can fill an important void in information gathering. While they do have some potential issues with coverage, completeness and false information, there is potential for the researcher to sort out the "good" responses. This chapter looks at the validity of the responses collected and also includes a detailed analysis of the representativeness of the responses collected.

## 5.2 Survey Design

The goal of the survey was to understand passengers' behavior on a recent trip on the Uxbridge Corridor and also to collect information on factors that may have influenced their behavior on the trip. To understand their behavior, respondents were asked a series of questions to identify their strategy. In addition, respondents were asked about details of their trip and their personal demographic characteristics. They were also asked to rate a series of statements to identify some attitudinal factors that may affect strategy choice. Appendix A contains a copy of the online survey used in this research. This section summarizes the types of questions that were asked.

The survey begins with statements that respondents rate from "strongly disagree" to "strongly agree". The aim of these statements is to assess passenger attitudes with regard to several factors that may influence their behavior. This includes their attitudes towards crowding, their relative preferences for walking, waiting, and in-vehicle time, their willingness to risk waiting for a later bus with and without information of the later bus's arrival, and their level of trust in countdown information.

Then, the survey asks respondents to describe their most recent trip from home on routes 207, 427, and/or 607. Passengers are asked to report the route(s) they took and the direction of the trip. Then they are provided with a dropdown menu with the appropriate stops and asked to select their boarding and alighting stops. To address the concern that some passengers may not remember the name of the stop they boarded or alighted at, a link to TfL's online map with labeled stops was provided. The option to select "I don't know" was also given. Passengers then indicated whether the trip was made on a weekday, a Saturday, or a Sunday, and in what time period. They were also asked for the addresses where they began and ended the journey and also asked how they got to and from where they boarded the bus. They were then asked about their trip purpose and whether or not they used countdown information both before going to the bus stop and at the bus stop.

Next, they were asked a series of questions to identify their route choice strategy for the trip. Figure 5-1 diagrams this series of questions. Passengers are first asked if they boarded the first bus that served their destination. If they answer yes, they may have a first bus strategy, but it is also possible that their preferred bus happened to arrive first. Therefore, a second question asks if they were waiting for a bus of a specific route. If they answer yes, they are given a second question, used only for validation. This question, identified in blue in Figure 5-1, asks them which route they were waiting for. If they understand the questions correctly, this route should match the route that they took. This provides a check of respondents' comprehension of the strategy identification questions. If they answer no to the question about waiting for a specific bus route, they are classified as first bus passengers. If passengers answered no to the first question, indicating that they did not board the first bus, this implies they have some form of a favorite bus strategy. They are then asked if they did not board a bus because it was too full. This helps identify if their choice to wait for a different bus had to do with crowding.

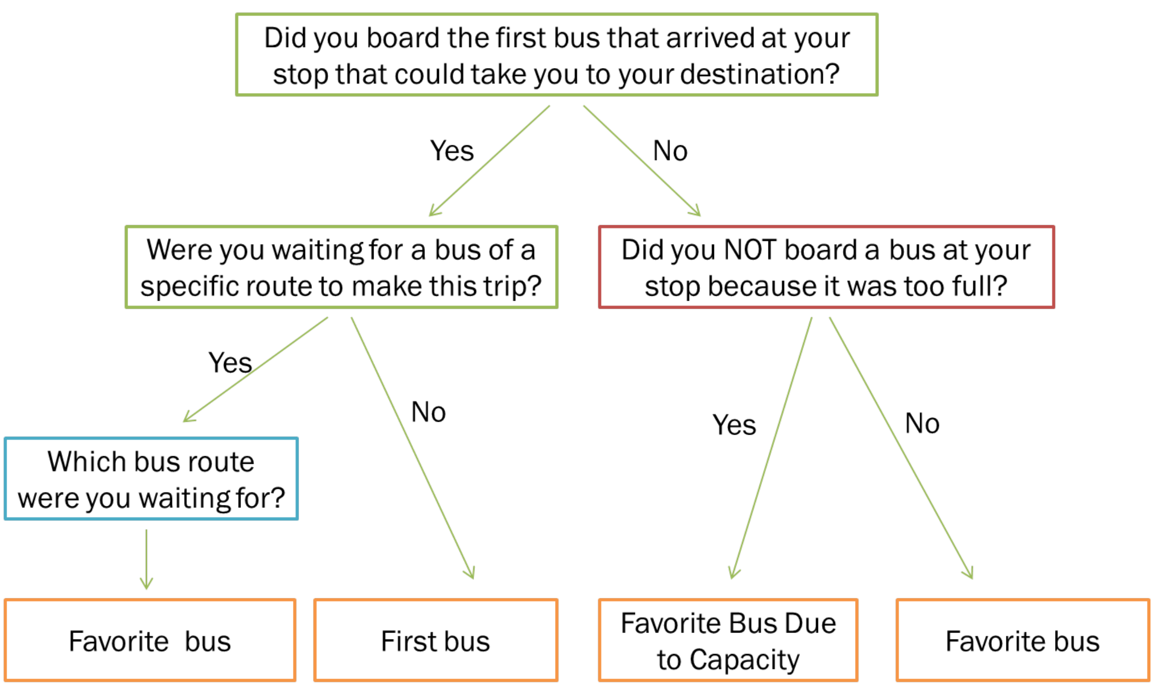



**Figure 5-1:** Survey Strategy Identification Questions

After answering this series of questions to identify their route choice strategy, respondents are asked to describe their most recent trip from somewhere other than home. They are asked an identical set of questions about the route they took, their boarding and alighting stops, the timing of the trip, where they started and ended the journey, and the trip purpose. Again, they are asked about their use of countdown information, and through the same set of questions, they are asked to identify their route choice strategy.

Finally, passengers are asked questions about their socio-economic characteristics. The survey asks their age, gender, income, and whether or not they have physical or mental impairments that make it difficult or impossible for them to walk to a bus stop or stand on a bus.

## 5.3 Survey Administration and Response Rates

The survey was sent via an email that introduced the survey and included a link to the survey. Figure 5-2 shows the email that was sent for the final version of the survey.

**To:** [Email]
**From:** "TfLAnalyticsSurve@tfl.gov.uk via surveymonkey.com" <member@surveymonkey.com>
**Subject:** Take a brief survey from TfL to win an iPad!
**Body:** Dear [FirstName] [LastName],

We are conducting a survey into the use of buses in the Ealing and Hillingdon boroughs, and we would appreciate your help by completing an online survey. The survey will take about ten minutes to complete, and your response will help us better understand our customers' preferences.

Respondents will be entered into a drawing to win an iPad. The winner will be selected at random from all responses received by March 12th. The winner will be notified via email on March 13th and asked to provide an address for delivery of the iPad.

Please click on the link to access the survey:

https://www.surveymonkey.com/s.aspx

Please be assured that your e-mail address has been randomly selected from our database of registered Oyster users. Please do not reply to this email as the mailbox is not monitored.

Many thanks in advance for your participation.

Yours faithfully,

TfL Analytics Team

If you do not wish to receive further emails from us about online surveys, please click the link below, and you will be automatically removed from our survey mailing list.

https://www.surveymonkey.com/optout.aspx

**Figure 5-2:** Survey Email

The survey was first administered to a pilot group of 392 people. The overall response rate was 9.1%. Four different configurations of the survey were tested. One included both the links to the map and a progress bar indicating how much of the survey the respondent had completed. The second included only the map links. The third included only the progress bar. And the fourth included neither map links nor a progress bar. The rate of survey completion was highest among those who were sent the survey with the map links and the progress bar so both were included in the final version of the survey.

A few issues were identified in the pilot. First, respondents were unwilling to provide their home address. Therefore, when asking about the trip starting from home, respondents were asked to provide only the postcode for their starting location, rather than the complete address. Secondly, a large percentage of respondents indicated that they had taken two different routes for a single trip. This option was intended to capture only passengers who had transferred from one route to another as part of a one-way journey. A study of the processed Oyster data revealed that transfers of this sort are very uncommon. Only 3.5% of trips on the corridor include a transfer between the three corridor routes. Looking at the boarding and alighting stops provided, it seemed that the majority of reported transfer trips in the pilot survey were actually round trips in which passengers took different routes on the way there and back. To address this, the question about the route selected was further clarified. Passengers were advised, "You will be asked about two one-way trips, one from home and one from somewhere other than home. First, please tell us only about your one-way trip FROM HOME." In addition, the transfer options were also further clarified, saying "I took both routes 207 and 607 to reach my destination, changing from one bus to the other at a stop served by both routes."

In order to achieve a higher response rate in the actual survey, an incentive was offered. People who responded to the survey were entered into a drawing for an iPad. The survey was sent out on February 20th to all passengers with at least one trip on the corridor between February 4th and February 17th, who had provided an email address with their Oyster card. A reminder email was sent once a week until the survey was closed on March 12th. The initial invitation email and the reminder emails were sent on midweek afternoons, as this has been found to be the time that garners the highest response rates. 52,490 people were emailed and 9,476 responses were collected, for a response rate of 18.1%. Section 5.4 discusses how response rates varied for different groups and addresses the overall representativeness of the survey.

Within the 9,476 responses collected, many responses were incomplete. Excluding transfers, Table 5.1 shows that only 5,555 people selected a route for their most recent trip from home and 5,051 people selected a route for their most recent trip from somewhere other than home. Of these reported trips, many aspects were incomplete. Overall, 85.9% of those who specified a route provided logical boarding and alighting stops. Logical boarding and alighting stops are defined as instances where the alighting stop is farther along the route than the boarding stop. Of the 14.1% of responses that did not provide a logical boarding and alighting stop, about half had left one of the response fields blank or reported "I don't know." The other half selected boarding and alighting stops, but they did not represent logical forward progress in the direction the individuals had indicated they traveled. While the other issues with completeness likely represent survey fatigue, unwillingness to provide certain information, or failure to remember details, the approximately 7% of responses with illogical boarding and alighting stops are indicative of some level of confusion with the basic survey questions and structure.

**Table 5.1:** Completeness of Survey Responses

| | From Home | From Somewhere Other Than Home | Total Trips |
|---|---|---|---|
| Selected a single route | 5555 | 5051 | 10606 |
| *and* | | | |
| Reported logical boarding and alighting stops | 4837 | 4278 | 9115 |
| *and* | | | |
| Provided day and time | 4116 | 3726 | 7842 |
| *and* | | | |
| Provided origin address/ postcode | 3593 | 2406 | 5999 |
| *and* | | | |
| Provided destination address | 2601 | 2111 | 4712 |
| *and* | | | |
| Provided Strategy | 2402 | 2103 | 4505 |

## 5.4 Representativeness of Survey Responses

Ideally, survey responses are representative of the overall corridor use. However, in online surveys like this one, there are several opportunities for response bias, leading to a sample that is not representative. First, only users who had provided TfL with an email address could be contacted about the survey. People who provided TfL with an email address may have different characteristics from those who did not. Of those who were emailed, many factors could influence their decision to respond. Therefore the respondents may not form a representative sample of those who were emailed. On another level, the information that respondents report in their survey may not be representative of their typical behavior, or of the typical behavior of respondents overall, due to reporting biases. This section considers several measurable dimensions to determine the extent and sources of bias in the survey responses. The factors considered include the proportion of trips made on each route, the average trip lengths, the frequency of corridor use, and the age of the individuals.

### 5.4.1 Selection Biases

In the web-based survey, selection biases can occur if those individuals who were emailed are not representative of corridor users. For the purpose of this analysis, the set of Oyster card users are considered to be the entire the population of corridor users, because the level of Oyster penetration by route on the corridor is between 98% and 99%. The next level of selection bias can occur if passengers who respond to the survey are not representative of those who were emailed. Each of these levels of selection bias are considered.

### Representativeness of Users with Emails Provided

Users of Route 427 are less likely to have provided an email address with their Oyster card than passengers on routes 207 and 607. Table 5.2 shows the number of distinct users on each route for ten weekdays in February 2013 and the quantity and percentage of these users who provided email addresses. All passengers who provided email addresses and had trips during these two weeks in February were contacted and asked to participate in the survey. This means that there was a small under-representation of Route 427 passengers in the sample of people invited to take part in the survey.

**Table 5.2:** Percent of Users who Provided Emails by Route

| | Distinct Users | Users Provided Email | % Provided Email |
|---|---|---|---|
| Route 207 | 111,783 | 30,594 | 27.4% |
| Route 427 | 79,733 | 19,927 | 25.0% |
| Route 607 | 75,336 | 20,783 | 27.6% |

The same pattern occurs when considering the proportion of trips taken on each route by Oyster users as a whole compared to the proportion of trips made on each route by people who supplied email addresses. These proportions, summarized in Table 5.3 indicate that passengers who provided email addresses are less likely to have used Route 427, and slightly more likely to have used routes 207 and 607, than Oyster users overall. While 28.1% of trips on the corridor were made on Route 427, when limiting the scope to Oyster users with emails provided, only 25.3% of trips are made on Route 427.

**Table 5.3:** Proportions of Trips Made on Each Route

| | All Oyster Users | Oyster Users Emailed |
|---|---|---|
| Route 207 | 0.467 | 0.481 |
| Route 427 | 0.281 | 0.253 |
| Route 607 | 0.252 | 0.266 |

Passengers on Route 427 tend to be older than on other routes. This is true both in terms of the percent of unique users who are elderly and in the percent of trips on the route made by elderly people. In the Oyster data, elderly people were identified by the use of the Freedom Pass, which enables London borough residents who are 60 or older to travel for free on public transit. For the ten weekdays in February that were considered, 12.3% of unique users of the corridor used the Freedom Pass for older adults. When considering only passengers with trips on Route 427, this percentage increases to 13.5%. Route 607 has the lowest rate of the Freedom Pass usage, with only 10.8% of passengers using the Freedom Pass for older people. Approximately 10.8% of trips on the corridor are made by elderly users holding Freedom Passes. These trips are not evenly distributed on the three routes. 11.1% of trips on Route 207, 12.1% of trips on Route 427, and 8.5% of trips on Route 607 are made by older adults using Freedom Passes.

A Freedom Pass for disabled users is also available. However, the usage of the disabled freedom pass on the corridor is much lower. Just 3.5% of trips are made by disabled users.

Disabled users are somewhat less likely to make trips on Route 607. 2.8% of trips on Route 607 are made by holders of the Freedom Pass for disabled users, compared to 3.7% on Route 207 and 3.9% on Route 607. The proportions of passengers and trips on the three routes that are elderly and disabled, according to Freedom Pass usage, are summarized in Table 5.4.

**Table 5.4:** Percentages of Elderly and Disabled Users

| | % Elderly Users | % of Trips Made by Elderly Users | % Disabled Users | % of Trips Mady by Disabled Users |
|---|---|---|---|---|
| Route 207 | 12.4% | 11.1% | 3.6% | 3.7% |
| Route 427 | 13.5% | 12.1% | 3.8% | 3.9% |
| Route 607 | 10.8% | 8.5% | 3.4% | 2.8% |

The lower ridership by elderly and disabled users on Route 607 is likely due to the greater distances between stops, requiring potentially longer access and egress distances. The differences between Route 207 and Route 427 passengers may be due to the patterns of land use and development and the generators of trips along the route. Route 207 serves Shepherd's Bush Station, Shepherd's Market Station, and White City Bus Station, which connect to the Underground's Central Line into Central London, as well as the Overground, and National Rail. Route 427, in contrast, serves the more outlying stops in Uxbridge.

The elderly population is much less likely to provide an email address with their Oyster card than the population in general. Of the Oyster users in the period considered, 26.9% provided email addresses. In contrast, only 3.9% of elderly Freedom Pass users provided email addresses. Disabled users are even less likely to provide an email address. Only .2% of disabled users on the corridor provided email addresses. Table 5.5 summarizes this information.

**Table 5.5:** Provision of Email Addresses by User Type

| | All Corridor Users | Users Emailed | % Emailed |
|---|---|---|---|
| Total | 161684 | 43472 | 26.9% |
| Elderly | 19846 | 781 | 3.9% |
| Disabled | 5604 | 9 | 0.2% |
| Infrequent Users | 44506 | 12202 | 27.4% |
| Frequent Users | 33059 | 9517 | 28.8% |

Another possible source of selection bias is that passengers who use public transit frequently may be more likely to provide their email addresses to TfL. In fact, Oyster users in general made on average 13.6 trips per person in the ten weekdays analyzed. Those emailed for this survey made on average 23.8 trips per person, suggesting that those people who provided email addresses are more frequent public transit users, on average. Frequency of public transit usage overall is likely to be correlated with frequent use of the corridor. This suggests that frequent users of the corridor may be oversampled. In fact, as reported in

Table 5.5, passengers who use the corridor frequently (nine or more times in ten days) are only slightly more likely to have provided emails than people who used the corridor just once in that period (infrequent users).

Table 5.6 shows the percentages of frequent and infrequent users on each route, considering the ten weekdays in February that were used to select survey recipients. Route 207 has the smallest percent of frequent users, defined as passengers with nine or more one-way trips over the ten-day period. Only 24.8% of Route 207's users qualify as frequent users by this definition, while 30.9% of Route 427 passengers are frequent users and 34.4% of Route 607 users use the corridor frequently. 21.2% of Route 207 passengers used the corridor just one time over the ten-day period (deemed infrequent users), significantly more than the proportion of Route 427 and Route 607 users with just one trip on the corridor.

**Table 5.6:** Frequent and Infrequent users on Each Route

| | % Frequent Users | % Infrequent Users |
|---|---|---|
| Route 207 | 24.8% | 21.2% |
| Route 427 | 30.9% | 14.2% |
| Route 607 | 34.4% | 12.6% |

With the exception of outbound trips on Route 607, the average trip length made by the users who were invited to take the survey were not substantially different from the overall averages for users on the corridor. Table 5.7 summarizes these trip lengths (in kilometers).

**Table 5.7:** Trip Lengths of Users Invited to Take the Survey

| | All Oyster Users | | Users Emailed | |
|---|---|---|---|---|
| | Inbound | Outbound | Inbound | Outbound |
| Route 207 | 2.75 | 3.01 | 2.67 | 3.02 |
| Route 427 | 3.29 | 3.28 | 3.27 | 3.31 |
| Route 607 | 5.68 | 5.87 | 5.66 | 6.06 |
| All Routes | 3.64 | 3.82 | 3.61 | 3.91 |

In summary, three main sources of selection bias were found at the level of email address provision.

- Users of Route 427 were slightly less likely to provide email addresses than users of routes 207 and 607. In addition, those individuals who provided email addresses had a smaller proportion of their trips on Route 427 than the corridor Oyster users overall.
- Elderly and disabled users were far less likely to provide email addresses.
- Those individuals who provided email addresses had more trips on public transportation in London, on average, than the average London Oyster user.

Route 427 serves more elderly and disabled users than the other routes, so it is possible that the under-representation of Route 427 passengers at this level is simply a result of under-representation of elderly and disabled users.

**Representativeness of Users Who Responded to the Survey Invitation**

Compared to the group of Oyster users who were emailed, those who responded to the survey had a smaller proportion of their trips on Route 427 (see Table 5.8) according to the Oyster data for the survey ID's that responded to the survey. This suggests that passengers who use Route 427 were less likely to respond to the survey invitation. However, the under-representation at this level is quite small.

**Table 5.8:** Proportions of Trips Made on Each Route by Survey Respondents

| | Oyster Users Emailed | Users Who Responded |
|---|---|---|
| Route 207 | 0.481 | 0.485 |
| Route 427 | 0.253 | 0.246 |
| Route 607 | 0.266 | 0.269 |

While very few elderly and disabled users were invited to participate in the survey, the response rate for elderly and disabled users is higher than the overall response rate for the survey. Of those who provided email addresses, 28.6% of elderly Freedom Pass holders responded to the survey, compared to an 18.2% response rate overall. Disabled Freedom Pass users were also slightly more likely to respond, with a 22.2% response rate, although the sample size is very small, with only nine disabled users receiving the survey. Table 5.9 summarizes these findings.

**Table 5.9:** Survey Response Rates by User Type

| | Users Emailed | Users Who Responded | % Responded (of those emailed) |
|---|---|---|---|
| Total | 43472 | 7893 | 18.2% |
| Elderly | 781 | 223 | 28.6% |
| Disabled | 9 | 2 | 22.2% |
| Infrequent Users | 12202 | 2155 | 17.7% |
| Frequent Users | 9517 | 1783 | 18.7% |

In the email inviting individuals to take part in the survey, they were told that the survey was designed to "better understand customers' preferences" and was focused on bus use in the Ealing and Hillingdon boroughs. Passengers who regularly use buses in these boroughs may have been more interested in sharing their experiences. Therefore it was hypothesized that frequent users would be more likely to respond to the survey. In fact, those passengers who had used the corridor frequently were only very slightly more likely to respond (18.7%) than passengers with just one trip on the corridor (17.7%).

Like the average trip lengths of those users who were emailed, the average corridor trip lengths for the respondents were also representative of overall users on the corridor. Table 5.10 shows that the average trip lengths (in kilometers) by route for respondents are almost identical to the average trip length by route for the group of users who were emailed.

**Table 5.10:** Average Trip Lengths for Survey Respondents

| | Users Emailed | | Users Who Responded | |
|---|---|---|---|---|
| | Inbound | Outbound | Inbound | Outbound |
| Route 207 | 2.67 | 3.02 | 2.63 | 2.96 |
| Route 427 | 3.27 | 3.31 | 3.26 | 3.35 |
| Route 607 | 5.66 | 6.06 | 5.63 | 6.12 |
| All Routes | 3.61 | 3.91 | 3.60 | 3.88 |

Those individuals who responded to the survey invitation form a fairly representative sample of those who were emailed. They deviate from those emailed three ways:

- Those individuals who responded take a slightly smaller percentage of their corridor trips on Route 427.
- Elderly and disabled users were far more likely to respond to the survey, but only a very small sample of these users were surveyed.
- Frequent users of the corridor were slightly more likely to respond to the survey than infrequent users.

### 5.4.2 Reporting Biases

In the survey, each respondent was asked to report their most recent trip on the corridor from home, and their most recent corridor trip from somewhere other than home. Of those trips described in the survey, only 18.9% were reported to have been on Route 427. This is lower than would be expected given the proportion of trips on each route made by individuals who responded to the survey. Table 5.11 summarizes the proportions of trips on each route that were reported in the survey compared to those that would be expected based on the Oyster card activity of the survey respondents. In addition to the under-reporting of trips on Route 427, there is an over-reporting of trips on Route 607 and slight under-reporting of trips on Route 207.

**Table 5.11:** Proportions of Trips Reported on Each Route

| | Users who Responded | Routes Reported in Survey |
|---|---|---|
| Route 207 | 0.485 | 0.478 |
| Route 427 | 0.246 | 0.189 |
| Route 607 | 0.269 | 0.333 |

There are several reasons respondents may have for over-reporting trips on Route 607 and under-reporting trips on the local routes. First, as Table 5.12 shows, and as will be discussed later in this section, passengers seem to be more likely to report longer trips, even though the average trip lengths of respondents overall is similar to the average trips on the corridors. This means that passengers with trips on both local and limited stop routes may have been more likely to report their limited stop route trips, perhaps because they were longer. While passengers were asked to report their most recent trips from home and from somewhere other than home, they may have forgotten very short trips they made or they may have felt they were not significant enough to report. In addition, passengers who favor Route 607 may have reported their Route 607 trip even if they have trips on the local routes as well because they hope that reporting a trip on Route 607 may result in improved Route 607 service.

There may also be historical reasons for the bias. Route 607 was established in 1990, replacing a trolleybus of the same name. In 2002, TfL proposed the West London Tram, which would run the length of Route 607. It was heavily opposed, with the local councils of Ealing, Hammersmith and Fulham, and Hillingdon all voting against the scheme. As a result, the tram scheme was postponed indefinitely in 2007. Route 607 is seen as an alternative to the tram, which does not require the changes to city centers and streetscapes that the tram would have required. It is possible that some respondents reported Route 607 trips to show their support for Route 607 instead of the tram.

The historical development of routes 207 and 427 may also explain the fact that under-reporting of Route 427 trips was more severe than the under-reporting of Route 207 trips. Route 207 was established in 1960, and ran the entire length of the corridor to Shepherd's Bush. Route 427 was added much more recently, in 2005, splitting Route 207 in two, with the overlapping portion from Trinity Road to Acton Old Town Hall. Oyster data for passengers boarding and alighting in the central portion indicates that most passengers are aware of both local routes and do not favor one over the other. However, passengers may have difficulty remembering which of the routes they took on their most recent journey. Because Route 207 is more established, passengers who have been using the corridor for many years may be more likely to report Route 207. In addition, Route 207 was listed first on the survey, which may also have led to people selecting it over Route 427.

Additional reporting biases were seen in answers to questions about age and disabilities. In the survey, respondents were asked to select their age range from a series of ten-year ranges. Only 69.6% of respondents answered this question, and only 1.4% of those who responded indicated that they were over 60. This is somewhat lower than the expected value given that elderly Freedom Pass users make up 2.8% of respondents. This could be the result of higher rates of survey fatigue among older respondents. The question about age came at the end of the survey and some users stopped answering questions before getting to it.

In response to two separate questions about disabilities, 139 survey respondents indicated that they had a long-term physical or mental impairment that made it difficult or impossible for them to stand on a bus, and 185 respondents said they had an impairment making it difficult or impossible for them to walk. This is surprising given that only two holders of the Freedom Pass for disabled users responded to the survey. This could be due to the fact that not all disabilities qualify for a Freedom Pass. In addition, respondents may hope that by responding "yes" to these questions about impairments, they may get additional bus service, or service closer to their homes.

A final factor for consideration is whether the trip lengths reported in the survey are representative of trips taken by the respondents. Table 5.12 shows that the average reported trip lengths (in kilometers) for each route are longer than the average trip lengths taken by respondents on each route. This suggests that passengers over-report longer trips and under-report shorter trips. Longer trips may be more memorable for respondents or shorter trips may be deemed insignificant. Even though respondents were asked to report their most recent trips from home and somewhere other than home, they appear to be more likely to report longer trips than shorter trips.

**Table 5.12:** Average Reported Trip Lengths

| | Users Who Responded | | Reported Trip Lengths | |
|---|---|---|---|---|
| | Inbound | Outbound | Inbound | Outbound |
| Route 207 | 2.63 | 2.96 | 2.94 | 3.34 |
| Route 427 | 3.26 | 3.35 | 3.70 | 3.49 |
| Route 607 | 5.63 | 6.12 | 6.45 | 6.68 |
| All Routes | 3.60 | 3.88 | 4.29 | 4.45 |

In summary, several forms of reporting bias were identified:

- Trips on Route 607 were over-reported and trips on Route 427 were under-reported.
- Respondents may have over-reported disabilities.
- Respondents reported trips that were longer, on average, than would be expected given the average trip lengths of the respondents calculated from the Oyster data.

## 5.5 Survey Validity

The validity of the survey depends on the respondents' ability to correctly interpret the questions and provide accurate answers. There are a few indications that certain survey questions were difficult for passengers to interpret and answer.

As was previously noted, the pilot survey had a surprisingly high rate of transfer trips reported. Despite the attempts at clarification, this trend continued in the actual survey. 16.8% of those who selected a route for their trip indicated that they took multiple routes in the same one-way journey. Of the 2135 transfer trips reported, only 490, or 23% of these transfers had logical boarding and alighting stops representing forward progress. This makes up 3.8% of trips on the corridor, which is similar to the actual rates of transferring within the corridor observed in the Oyster data. In contrast, the other 77% of transfers reported appear to be examples of people misunderstanding the question. As noted previously, approximately 7% of those respondents who selected just one route also appeared to have misunderstood the question, providing illogical boarding and alighting stops. This means that overall, close to 20% of those who responded to the questions about which route they took seem to have misunderstood the question.

Another validity test was inserted into the questions identifying a passenger's strategy choice. Passengers who indicated that they were waiting for a specific bus route were asked which bus route they were waiting for. If they understood the question correctly, this route should match the route that they indicated they took for the trip. Of those who responded to the question, 79.4% responded with the same route that they had selected in the previous question about what route they took for the trip. This indicates that some respondents did not interpret the question as intended. These respondents may have a strategy in which they usually prefer a specific route but in this instance were not willing to wait for it. Thus, these respondents would be misclassified as favorite bus passengers when, in fact, they used a first bus strategy for this particular trip. Given that the validation question was included, those passengers whose answers did not match the previously selected route can be removed from the analysis.

## 5.6 Recommendations

Of the issues identified in terms of the representativeness and validity of the survey, some can be addressed fairly easily. Paper surveys could be mailed to the homes of elderly and disabled Freedom Pass users to make up for the fact that the online survey under-samples these users. Users of Route 427 could be oversampled relative to the other routes. To combat some of the reporting biases, respondents could be prompted with information about their most recent trip on the corridor, based on near real-time processed AFC data for each individual respondent. This would help them accurately remember the route they took and report their most recent trip regardless of trip length. Another option is to do post-analysis manipulation to select a set of responses from the survey data collected that is representative of the respondents' typical behavior.

The questions raised about the validity of answers to specific questions speak to the importance of question wording and the use of pilot surveys with and the collection of feedback from survey testers. Despite the use of a pilot and of a round of testing of the survey in this research, some answers reflect a lack of comprehension or attention to the questions asked. However, because online surveys can be sent to large numbers of people and many responses can be collected, those responses that are illogical or appear in-valid can be discarded from the analysis.

## 5.7 Conclusions

For an unsolicited survey, the 18.1% response rate that it garnered is fairly high. Given the large number of users who have provided email addresses to TfL, this method was able to collect a large number of responses with information on a wide set of variables, ranging from indicators of passenger attitudes to age, income, and gender data, to details about the individuals' recent trips on the corridor. An onboard survey would not have been able to collect this much information, and an interview-based face-to-face survey would not have been able to reach as many individuals. More than 9,000 people responded to the survey, and they provided complete, valid information about 4,505 trips. Compared to other survey methods, the online survey was able to be implemented at a small fraction of the cost.

Some selection biases were found, but in most cases, the level of over or under-representation is very small. Most notably, there is a substantial under-representation of elderly and disabled passengers, because these individuals are less likely to provide email addresses. This could be addressed through targeted over-sampling or use of mail-out surveys for these populations. Reporting biases were also observed. Respondents were more likely to report on trips they took on Route 607 and less likely to report trips they took on Route 427. Considering each route separately, passengers were more likely to report trips longer trips. These biases can be combated either through the use of smartcard information to help respondents improve the accuracy of their reporting or through post-analysis selection of survey results. Finally, some users appear to have been confused by certain questions, and there was some amount of incompleteness, likely due to a combination of survey fatigue and passengers failing to remember certain details. Despite these issues, the benefit of an online survey, conducted at a very low cost, is that large volumes of data can be collected such that problematic responses can be discarded and a large sample size remains for analysis. This suggests that web-based surveys represent a viable, effective, and efficient way to collect detailed information from a large number of public transportation users.

# Chapter 6

# Web-Based Survey Findings

This chapter provides a set of descriptive statistics and analyses that summarize those factors measured in the survey that may affect route choice strategy. Ultimately, the best way to assess the magnitude of the effect of each factor and their trade-offs is likely to be in the form of a model. This preliminary descriptive analysis can inform the structure and specification of the model.

This analysis begins with the factors that were already considered using the probabilistic model method: trip length, crowding, use of countdown information, and frequency of corridor use. In addition, it explores other factors captured in the survey including attitudes, age, income, gender, trip purpose, and time of day. On the Uxbridge Corridor, strategy choice consists of two decisions: first, the decision of which stop to board at, and then the decision of which bus to board at that stop. The majority of the survey analysis in this chapter focuses on the second decision: which bus to board at a stop. This analysis is restricted to OD pairs served by the limited stop service route, Route 607. In addition, OD pairs served by additional routes other than routes 207, 427, and 607 are removed from the analysis, as the passengers boarding and alighting at these pairs have a different route choice set. Invalid responses, in which a respondent indicated that they were waiting for a specific route but the route they reported did not match the route they took, or provided illogical boarding and alighting stops, were also excluded.

At the end of this chapter, a brief overview of the level of consistency between the results of the probabilistic model and of the survey results is provided along with some concluding remarks. Th survey data presents many more opportunities for analysis. Some possibilities are described in Chapter 8.

## 6.1 Trip Length

First, the influence of trip length is considered. In order to maintain sufficient sample sizes, all reported week day trips are included, regardless of time of day. Tables 6.1 and 6.2 show the proportion of responses that fall into each strategy type for shorter and longer trips in Market 1 (OD pairs served by routes 427 and 607 only) and Market 2 (OD pairs served by routes 207 and 607 only). Trip length is defined in terms of the number of minutes the trip typically takes on Route 607.

**Table 6.1:** Strategies by Trip Length in Market 1

| | First Bus | Favorite Bus: Route 427 | Favorite Bus: Route 607 | Sample Size |
|---|---|---|---|---|
| Less than 20 minutes | 0.292 | 0.085 | 0.623 | 106 |
| 20 minutes or more | 0.056 | 0.034 | 0.910 | 177 |

**Table 6.2:** Strategies by Trip Length in Market 2

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Sample Size |
|---|---|---|---|---|
| Less than 20 minutes | 0.356 | 0.234 | 0.411 | 526 |
| 20 minutes or more | 0.123 | 0.211 | 0.667 | 261 |

In both markets, the preference for Route 607 increases with trip length, as was found in the analysis of the Oyster data. For shorter trips, some people prefer the local routes, which is likely because they tend to be less crowded. In Market 2, the preference for Route 207 is especially strong: 23.4% for shorter trips and 21.1% for longer trips. This is likely because the boarding stops at the beginning of Market 2 tend to be the most crowded along the route. As was seen in the analysis of AVL and AFC data, for shorter trips, avoiding crowded buses seems to be more important than for longer trips when the crowded Route 607 buses offer substantial time savings.

## 6.2 Crowding

In the inbound AM peak, several stops in the middle of the corridor have very high median and 90th percentile loads on Route 607. The analysis of the automated data suggested that this crowding may have tempered passengers' preference for Route 607 buses and increased their preference for the slower but less crowded Route 207 buses, particularly for shorter trips. Most of the crowded stops are found in Market 2. Therefore the crowding analysis focuses on survey responses from this market, with the sample restricted to inbound trips in the AM peak, when most of the crowding occurs. Passengers who boarded at stops where the median Route 607 AM peak loads are greater than 70 people are compared to passengers who boarded at stops with more moderate Route 607 loads.

While passengers experience the departing load from the stop they boarded at, they may be influenced by the arriving load on the vehicle. The first analysis designates stops as crowded or uncrowded according to their departing load (Table 6.3), while the second set of analysis groups stops by their arriving load (Table 6.4). In both cases, passengers at the crowded stops were more likely to take Route 607, contrary to the hypothesis. These passengers also tend to take longer trips, particularly when trips are grouped by the arriving load.

An interesting aspect is that of those who are waiting for a specific bus route (either Route 207 or Route 607), a greater proportion of those boarding at crowded stops indicated that they did not board the first bus to arrive that served their destination because it was too full to board. That is, at the crowded stops, those who do not board the first bus are more

**Table 6.3:** Strategies at Crowded and Uncrowded Stops, Using Departing Load

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Too Full to Board (% of Favorite Bus Passengers) | Average Trip Length | Sample Size |
|---|---|---|---|---|---|---|
| Crowded Stops | 0.361 | 0.174 | 0.465 | 0.222 | 12.0 | 155 |
| Uncrowded Stops | 0.348 | 0.213 | 0.438 | 0.121 | 14.0 | 89 |

**Table 6.4:** Strategies at Crowded and Uncrowded Stops, Using Arriving Load

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Too Full to Board (% of Favorite Bus Passengers) | Average Trip Length | Sample Size |
|---|---|---|---|---|---|---|
| Crowded Stops | 0.286 | 0.114 | 0.600 | 0.280 | 22.7 | 35 |
| Uncrowded Stops | 0.318 | 0.172 | 0.510 | 0.097 | 13.0 | 151 |

likely to do so because of crowding. In some cases, passengers who chose to board Route 607 did so even after not boarding a previous bus because it was too full. This suggests that when Route 607 buses are very full, some passengers may choose to wait for a second Route 607 bus rather than choosing to take Route 207 instead.

## 6.3 Countdown Information

Most of the Route 607 stops have countdown signs informing passengers of the number of minutes until approaching buses arrive at the stop. Some passengers may choose not to look at the countdown signs, while others may board at a stop without countdown information, but may look up the same information on the mobile phones. The survey asks passengers directly whether or not they used countdown information at their boarding stop to choose which bus to board.

The effect of countdown information on strategy choice is not obvious. It seems logical that depending on the information presented, passengers may behave differently. If the countdown information indicates that the wait for Route 607 is long, this information may sway the passenger to board the first bus that arrives. In contrast, if the countdown information indicates that a Route 607 bus is arriving shortly after a local bus, having this information may lead passengers to wait for Route 607, using a favorite bus strategy. According to the inferences of the probabilistic model, passengers appeared to be more likely to wait for Route 607 at stops with countdown signs. This suggests that information alters their opinions of their route choice options. It may imply that passengers find waiting less onerous when they know the length of the wait. With less uncertainty regarding waiting time, Route 607, with longer headways but shorter in-vehicle times, becomes more appealing.

According to the survey data, the same effect is captured when considering passengers in Market 2. As shown in Table 6.5, passengers who used countdown information are more likely to prefer Route 607 and less likely to use a first bus strategy. This supports the hypothesis that people find the waiting time for Route 607 more tolerable when they know how long the wait is. Some of these passengers may also be using countdown information on a mobile device to time their arrival at the stop.

**Table 6.5:** Strategies and Use of Countdown Information in Market 2

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Used countdown | 0.248 | 0.206 | 0.546 | 19.1 | 436 |
| Did not use countdown | 0.377 | 0.274 | 0.349 | 17.4 | 321 |

All of the boarding stops in Market 1 have countdown signs. However, only half of the Market 1 passengers reported using countdown information to decide which bus to board. This implies that many passengers have already decided on their strategy and feel that their route choice decision does not benefit from the information on the countdown sign. In Market 1, the strategies of those who used countdown information are almost identical to those of people who did not use countdown information to make their decision (see Table 6.6). Most trips in Market 1 are very long, leading to a strong preference for Route 607. This preference appears to outweigh any effect of the use of countdown information in this market.

**Table 6.6:** Strategies and Use of Countdown Information in Market 1

| | First Bus | Favorite Bus: Route 427 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Used countdown | 0.135 | 0.064 | 0.801 | 26.3 | 141 |
| Did not use countdown | 0.155 | 0.042 | 0.803 | 27.3 | 142 |

Respondents who used countdown information were more likely to wait for Route 607 buses regardless of their trip length (See Table 6.7). This is interesting because, on average, waiting for a Route 607 bus for a trip that is less than ten minutes long will result in a longer overall expected travel time than simply taking the first bus. It is possible that people who use countdown information are able to disregard this default assessment in instances where they see that a Route 607 bus is arriving soon. It is also possible that people over-estimate the in-vehicle time savings of taking a Route 607 bus.

## 6.4 Frequency of Corridor Use

Survey responses were linked to Oyster data to determine how many trips individuals took on the corridor in the two-week period prior to the start of the survey. Respondents who had taken six or more trips in this time were designated as frequent users, while those with just one trip in the period were infrequent users. Frequent users may be more knowledgeable

**Table 6.7:** Strategies with and without Countdwon Information by Trip Length

| Trips of less than 10 minutes | | | | |
|---|---|---|---|---|
| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Sample Size |
| Used Countdown | 0.326 | 0.250 | 0.424 | 92 |
| Did not use countdown | 0.463 | 0.274 | 0.263 | 95 |
| **Trips of 10 to 30 minutes** | | | | |
| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Sample Size |
| Used Countdown | 0.278 | 0.222 | 0.500 | 252 |
| Did not use countdown | 0.277 | 0.262 | 0.461 | 191 |
| **Trips of more than 30 minutes** | | | | |
| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Sample Size |
| Used Countdown | 0.087 | 0.120 | 0.793 | 92 |
| Did not use countdown | 0.200 | 0.200 | 0.600 | 60 |

of the corridor and more aware of the time savings that can be accrued from taking Route 607. This would lead one to expect frequent users to be more likely to wait for Route 607. Tables 6.8 and 6.9 show the behavior of users from these two groups. In Table 6.8, frequent users appear to be less likely to wait for Route 607, contrary to the hypothesis. However, frequent users also take trips that are on average six minutes shorter (in terms of Route 607 in-vehicle time) than the trips of infrequent users.

**Table 6.8:** Strategies of Frequent and Infrequent Users

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Frequent | 0.292 | 0.206 | 0.502 | 16.0 | 325 |
| Infrequent | 0.240 | 0.240 | 0.521 | 22.1 | 146 |

**Table 6.9:** Strategies of Frequent and Infrequent Users, Controlling for Trip Length

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Frequent | 0.267 | 0.207 | 0.525 | 20.0 | 217 |
| Infrequent | 0.240 | 0.240 | 0.521 | 22.1 | 146 |

Table 6.9 attempts to control for this by removing trips of less than ten minutes taken by frequent users. This brings the difference in average trip lengths to just two minutes. In this case, frequent users and infrequent users are essentially equally likely to prefer Route 607, indicating that even infrequent users of the corridor are aware of the different options and their characteristics. Infrequent users are somewhat more likely to wait for Route 207.

This could indicate a lack of knowledge or a preference among infrequent users for less crowded buses. It may also have to do with the typically different trip purposes of frequent and infrequent users.

## 6.5 Passenger Attitudes

Survey respondents were asked eight questions that aimed to assess their attitudes towards certain factors thought to influence strategy choice. Three of the questions focused on crowding. Two questions considered passengers' level of risk aversion with and without knowledge of future bus arrivals, and a related question asked about their levels of trust in information about future arrivals. Two questions compared waiting and walking time, respectively, to in-vehicle time.

Responses to the questions about crowding (see Figure 6-1) show that most passengers are willing to board buses even if they cannot get a seat, but many passengers will not try to board buses that are very full. Only 8% agreed or strongly agreed that they would only board a bus if they could get a seat. However, 43% of respondents disagreed or strongly disagreed with the statement "I will try to squeeze onto a bus, even if the bus appears very full." Similarly, 43% of respondents agreed or strongly agreed with the statement, "If a bus is very crowded, I will wait for a less crowded bus," suggesting that very high levels of crowding play a strong role in passengers' bus selection.

Other questions revealed that levels of risk aversion in the sample are dependent on the access to information about future arrivals. Nearly half of respondents (48%) agreed or strongly agreed with the statement, "If I don't know when each bus will arrive, I will take the first bus that arrives at my stop, even if a faster bus serves my destination." This shows a low willingness to take on risk without information about arrivals. In contrast, respondents overwhelmingly indicated a willingness to wait for a faster bus, if they knew it would arrive soon. 72% of respondents agreed or strongly agreed with the statement, "If I know a faster bus will arrive soon, I will wait for it, even if a slower bus is at my stop." This suggests that passengers would have very different strategies with and without information on future bus arrivals.

These statements mark the extremes of access to information, with one statement indicating that the respondent has no knowledge of arrivals, and the second indicating that the passenger knows (presumably with certainty) that a bus will arrive soon. In reality, passengers learn of arrivals from countdown information either on signs at the bus stop or on their phone or some other device. Passengers may trust this information to varying degrees.

The final question regarding attitudes toward information attempted to determine to what extent passengers think that countdown information is accurate. This question asked passengers to rate the statement, "Countdown information often indicates that buses will arrive sooner than they actually do." The responses were almost perfectly symmetrical. 27% said they neither agreed nor disagreed, 38% agreed, and 35% disagreed. Of those who agreed, only 9% indicated that they strongly agreed. Therefore, distrust of countdown information does not appear to be a major issue for the respondents overall. Responses to the three questions about risk aversion and trust of information are displayed in Figure 6-2.

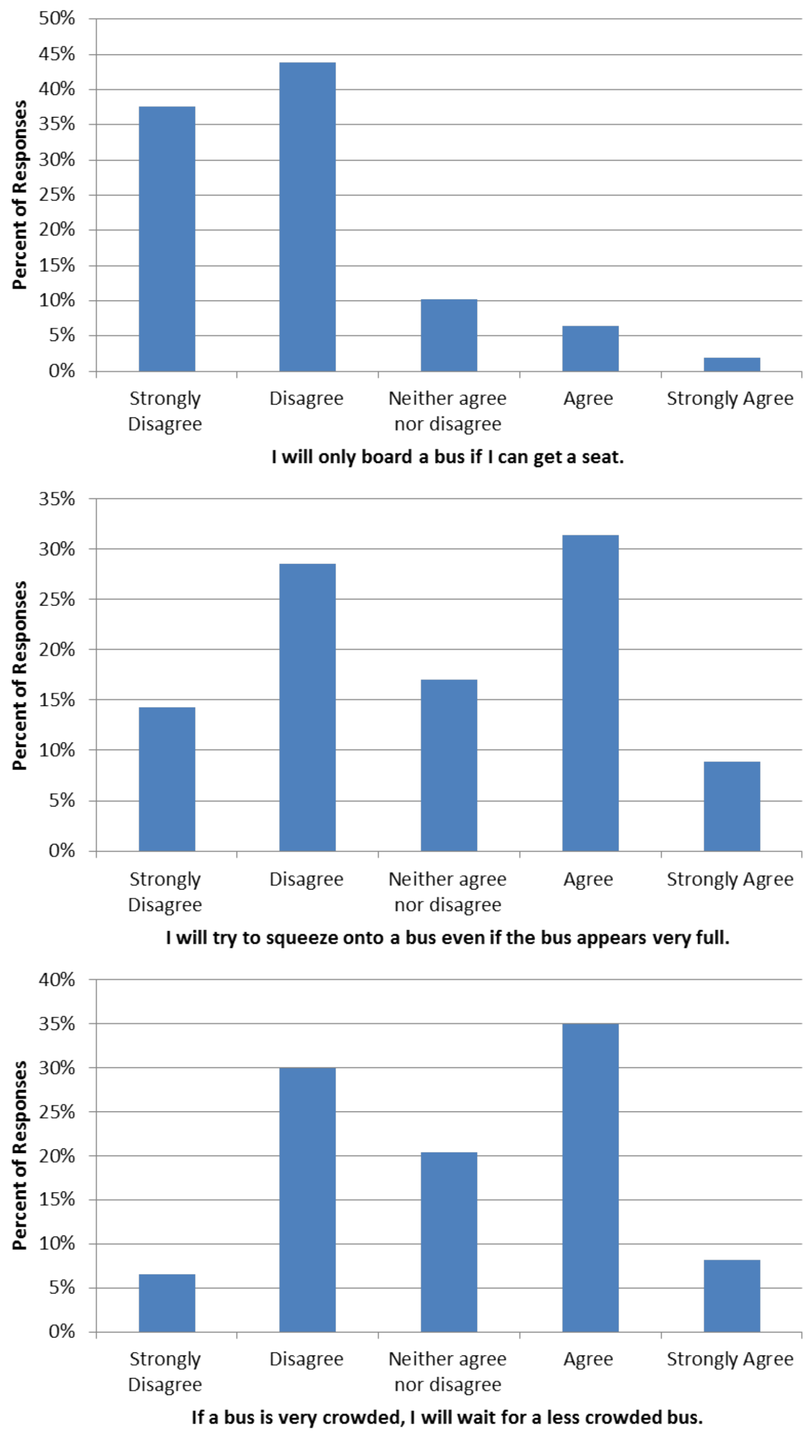



**Figure 6-1:** Attitudes Towards Crowding

Finally, respondents were asked questions about their opinions of trade-off between waiting and walking time and in-vehicle time. Respondents to the prompt "I prefer spending longer on a bus if it means spending less time waiting at a stop," were more likely to agree than disagree. 50% agreed, while 26% were neutral and only 24% disagreed. The statement

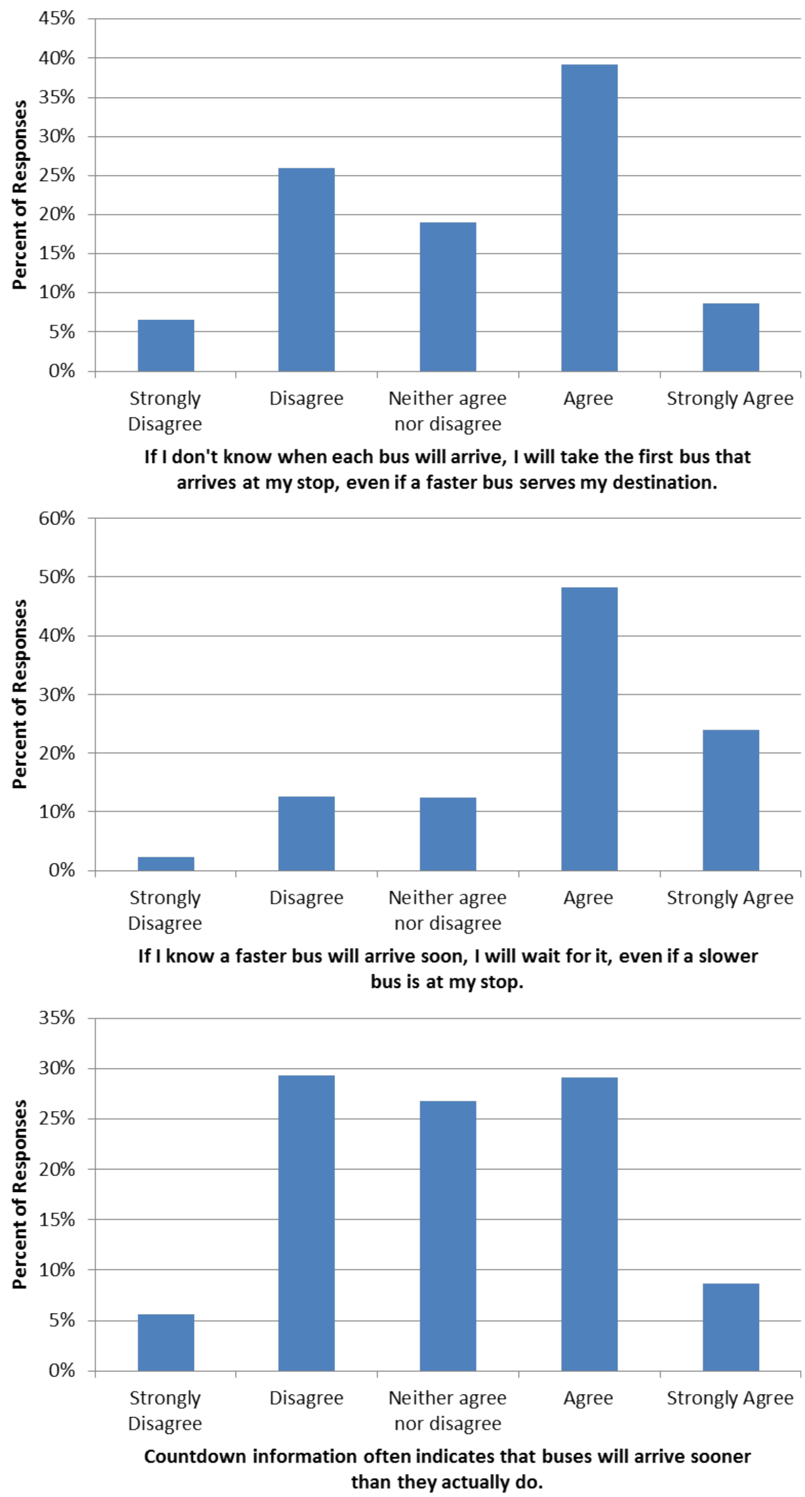



**Figure 6-2:** Attitudes Towards Risk and Information

was deliberately vague about the overall time savings, but the responses reveal the strong distaste for waiting time that most people feel. The distaste for walking does not appear to be so severe. 48% of respondents agreed that they "don't mind walking longer distances to reach a stop served by faster buses," and only 30% disagreed. Figure 6-3 shows the responses to the waiting time statement and figure 6-4 displays responses to the walking time statement.

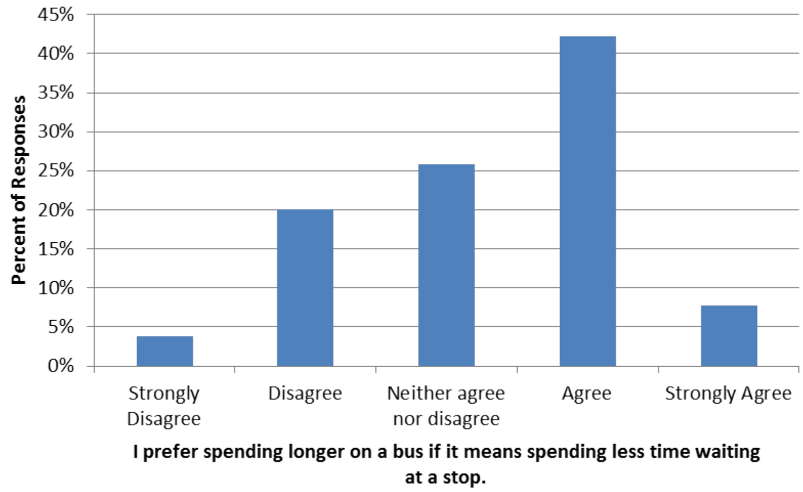



**Figure 6-3:** Attitudes Towards Waiting/In-vehicle Time Trade-off

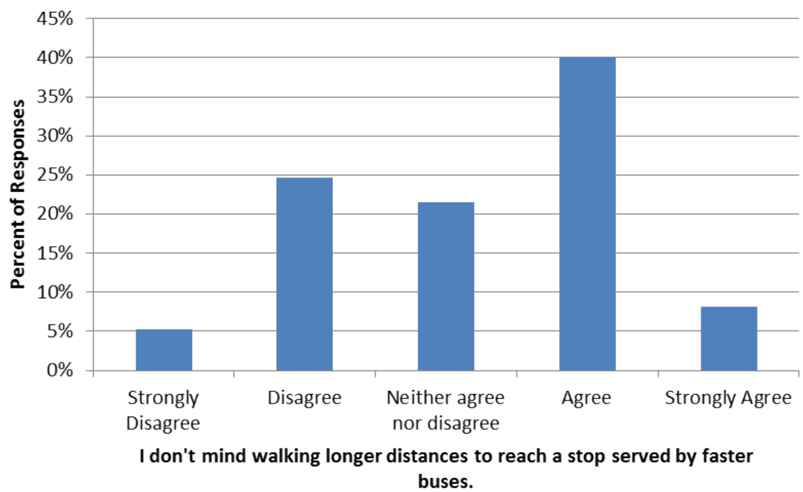



**Figure 6-4:** Attitudes Towards Walking/In-vehicle Time Trade-off

Analysis of the correlation of responses to the attitude questions with passenger strategies can determine whether these attitudes are strong predictors of route choice strategy. This analysis focuses on passengers who reported inbound weekday trips, boarding and alighting at OD pairs in Market 2.

### Crowding Sensitivity

Passengers who are more sensitive to crowding are expected to be more likely to prefer local buses and less likely to prefer the crowded Route 607 buses. Crowding sensitive people were defined as people who either disagreed or strongly disagreed with the statement "I will try to squeeze onto a bus, even if the bus appears very full," and agreed or disagreed with the statement, "If a bus is very crowded, I will wait for a less crowded bus." People who who had a neutral response to either question were excluded. Because only a small percentage of people indicated that they would not board a bus if they could not get a seat, that question was not used in the analysis.

When considering responses from all boarding stops and times of day, the expected pattern of behavior is not detectable in the data. As Table 6.10 shows, while people who are sensitive to crowding are slightly more likely to prefer the local route, they are also slightly more likely to prefer Route 607. The slight preference for Route 607 could be due to the fact that the people in the crowding sensitive group take slightly longer trips, on average. In addition, this considers all responses for weekday trips. Crowding is only an issue at select stops in select periods.

**Table 6.10:** Strategies by Sensitivity to Crowding

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Too Full to Board (% of Favorite Bus Passengers) | Average Trip Length | Sample Size |
|---|---|---|---|---|---|---|
| Crowding Sensitive | 0.244 | 0.252 | 0.504 | 0.229 | 20.5 | 266 |
| Crowding Insensitive | 0.292 | 0.236 | 0.472 | 0.065 | 18.2 | 216 |

Table 6.11 looks specifically at the differences in behavior between crowding sensitive and crowding insensitive people who reported trips during the AM peak, when crowding is an issue at some stops. It summarizes the route choice strategies of passengers who boarded at stops with very high Route 607 departing loads. At these crowded stops, crowding sensitive people are less likely to wait for Route 607 and are more likely to wait for Route 207 than people who are not sensitive to crowding. Route 207 tends to be less crowded, so it is not surprising that crowding sensitive people prefer it.

**Table 6.11:** Strategies by Sensitivity to Crowding at Crowded Stops

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Too Full to Board (% of Favorite Bus Passengers) | Average Trip Length | Sample Size |
|---|---|---|---|---|---|---|
| Crowding Sensitive | 0.282 | 0.308 | 0.410 | 0.214 | 10.8 | 39 |
| Not Crowding Sensitive | 0.366 | 0.171 | 0.463 | 0.115 | 11.6 | 41 |

Passengers who are crowding sensitive and reported that they did not board the first bus were much more likely to indicate that they did so because a previous bus that they wanted to board was too full. Considering all trips, 23% of crowding sensitive passengers reported that this was their reason for not taking the first bus compared to just 6.5% of passengers who are not sensitive to crowding. The perception that a bus is too full appears to vary considerably from person to person.

### Risk Aversion

There are clear differences in behavior between risk averse people and risk takers. These differences in behavior were observed both for trips where countdown information was not used and when it was.

First, trips in which countdown information was not used were considered. Passengers who agreed or strongly agreed with the statement, "If I don't know when each bus will arrive, I will take the first bus that arrives at my stop, even if a faster bus serves my destination," were considered risk averse, while passengers who either strongly disagreed or disagreed with that statement were grouped as risk takers. Passengers with a neutral opinion were not included. 54% of the risk takers prefer Route 607, while only 36% of of the risk averse group preferred Route 607. This shows that peoples' willingness to wait for a faster bus, be it intrinsic or learned, may play an important role in their decision-making. This produces variation among individual behavior even when the service and trip profile is held constant.

A similar pattern was seen when considering the behavior of passengers who used countdown information for their trips. This time, responses to the statement, "If I know a faster bus will arrive soon, I will wait for it, even if a slower bus is at my stop," were used to classify passengers as risk averse or risk takers. Risk averse people disagreed or strongly disagreed with the statement while risk takers agreed or strongly agreed. Again, risk takers were much more likely than the risk averse group to wait for a Route 607 bus. Interestingly, those in the risk averse group were more likely to prefer Route 207. Waiting for Route 207 is less risky because of the very short headways, but there is no clear logical explanation for this group's strong preference for Route 207. It may be a result of the uncertainty inherent from the small sample size of risk averse people. Tables 6.12 and 6.13 summarize the strategy choices for risk averse people and risk takers.

**Table 6.12:** Risk Aversion and Strategies Without Countdown Information

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Risk Averse | 0.445 | 0.191 | 0.364 | 16.6 | 173 |
| Risk Takers | 0.195 | 0.263 | 0.542 | 19.5 | 118 |

**Table 6.13:** Risk Aversion and Strategies With Countdown Information

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Risk Averse | 0.262 | 0.452 | 0.286 | 15.4 | 42 |
| Risk Takers | 0.248 | 0.167 | 0.585 | 19.7 | 371 |

### Level of Trust in Countdown Information

Next, the behavior of passengers who indicated that they trust countdown information is compared to the behavior of passengers who indicated some distrust. Only passengers who used countdown information are considered. Passengers who strongly disagreed or disagreed with the statement "Countdown information often indicates that buses will arrive sooner than they actually do," form the group of people who trust countdown while those who agreed or strongly agreed distrust countdown.

Surprisingly, passengers who distrust countdown were somewhat more likely to wait for a Route 607 bus. It is likely that the level of trust in countdown information is not a very important predictor of passenger behavior. This may be in part because passengers do not have very strong opinions on the accuracy of countdown information. Only 15% of people indicated that they either strongly agreed or strongly disagreed with the statement about countdown information. Even if passengers do not believe that the countdown information is perfectly accurate, this appears to not be a big enough factor to dissuade them from waiting for Route 607. Table 6.14 shows the strategies of those who trust and distrust countdown information.

**Table 6.14:** Strategies and Trust of Countdown Information

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Trust Countdown | 0.265 | 0.235 | 0.500 | 18.9 | 170 |
| Distrust Countdown | 0.250 | 0.153 | 0.597 | 19.2 | 144 |

### Trade-Off: Waiting Time and In-Vehicle Time

In response to the statement, "I prefer spending longer on a bus if it means spending less time waiting at a stop," passengers who agreed or strongly agreed are considered people who prefer in-vehicle time, while those who disagreed or strongly disagreed prefer waiting time. Those who prefer waiting time were more likely to have a favorite bus strategy, preferring Route 607. This makes sense because this strategy trades off more waiting time for shorter in-vehicle time. Again, this shows that individuals' personal attitudes can create variation even with external factors held constant. Table 6.15 shows the difference in behavior according to attitudes toward waiting and in-vehicle time.

**Table 6.15:** Strategies and Waiting/In-vehicle Time Trade-Off

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Prefer In-Vehicle Time | 0.310 | 0.229 | 0.461 | 17.9 | 371 |
| Prefer Waiting Time | 0.241 | 0.171 | 0.588 | 18.7 | 199 |

### Trade-off: Walking Time and In-vehicle Time

The final attitude statement, "I don't mind walking longer distances to reach a stop served by faster buses," influences the decision about which stop to board at rather than which bus to board once at a stop. At a broad level, passengers who elected to board at a local stop can be compared to passengers who boarded at combined stops served by limited stop buses as well as local buses. One expects passengers who are averse to walking to be more likely to board at local-only stops because they are closer together. This appears to be the case. Of those who boarded at local stops, 34.4% indicated that they either disagreed or strongly disagreed with the statement “I don’t mind walking longer distances to reach a stop served by faster buses.” This is compared to 29.8% of those who boarded at combined stop. This shows that the decision of which stop to board at may also be influenced by variation in personal taste.

## 6.6 Age and Disabilities

Very few older people responded to the survey. Only 1.3% of the weekday trips reported were made by people over 60. One might expect people older than 60 to be less likely to choose to walk to the limited stop bus stops, which are farther apart than the local route stops. Therefore, one would expect more representation of these older people at local-only bus stops than at the combined bus stops. This turns out to be the case, but only by a small margin. 1.4% of the reported boardings at local-only stops are by people over 60 compared to 1.2% at combined stops. Further analysis of actual access and egress distances would be needed to determine whether people over 60 elect to walk shorter distances than younger people.

For those passengers who decided to board at a combined stop, there is no clear reason for passengers of different ages to behave differently. An analysis of route choice strategies by age (in Table 6.16) shows that the youngest passengers are least likely to prefer Route 607 while passengers over 50 are most likely to wait for Route 607 buses. The trip lengths for the three age groups are similar so this variation may be due to some other factor, such as trip purpose, or variation in individuals’ value of time.

**Table 6.16:** Strategies by Age

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| 30 and under | 0.283 | 0.238 | 0.479 | 18.9 | 361 |
| 31 to 50 | 0.296 | 0.204 | 0.500 | 17.4 | 270 |
| Over 50 | 0.222 | 0.222 | 0.556 | 17.7 | 54 |

Another question on the survey asked respondents if they have “any long-term physical or mental impairment which makes it either difficult or impossible for [them] to walk.” People who responded yes to this question are expected to be more likely to board at local-only stops because the local-route stops are closer together. Of those who reported trips starting at a local-only stop, 2.3% responded yes to that question. In comparison, 1.9% of those who boarded at combined stops said yes to the question about a physical impairment. While this difference is not large, it is directionally consistent with the expectations.

## 6.7 Income

Income is often associated with value of time estimates. If this is the case, one expects that higher income respondents will be more likely to wait for Route 607 in order to gain the time savings it offers. In fact, the opposite trend occurs, as seen in Table 6.17. The highest income bracket are least likely to prefer Route 607 and the lowest income bracket are the most likely. However, this pattern can mostly be explained by the fact that higher income respondents take shorter trips than lower income respondents. On average, people making less than £20,000 made trips that take 23.7 minutes on Route 607, while people who make more than £50,000 take trips averaging just 14.1 minutes on the limited stop route.

**Table 6.17:** Strategies by Income

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Less than £20,000 | 0.204 | 0.238 | 0.558 | 23.7 | 206 |
| £20,000 to £50,000 | 0.297 | 0.233 | 0.470 | 16.6 | 279 |
| More than £50,000 | 0.380 | 0.169 | 0.452 | 14.1 | 166 |

Table 6.18 limits the analysis to trips of 20 minutes or longer in an attempt to hold trip length constant among the groups. With this control, the highest income group become the most likely to wait for Route 607. The low income group is still slightly more likely to wait for the limited stop service than the middle income group, but this may be accounted for by the fact that their trips are, on average, about two minutes longer in terms of Route 607 in-vehicle time. The sample size for the high income group is small, suggesting a high degree of uncertainty in the estimate. Still, the very high incidence of a favorite bus strategy preferring Route 607 among the highest income group suggest that income may in fact have the hypothesized effect. Higher income people may have a higher value of time, encouraging them to wait for the Route 607 bus for the longer trips in which time savings are significant.

**Table 6.18:** Strategies by Income, Trip Length Controlled

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Less than £20,000 | 0.159 | 0.177 | 0.664 | 33.5 | 113 |
| £20,000 to £50,000 | 0.148 | 0.247 | 0.605 | 31.7 | 81 |
| More than £50,000 | 0.080 | 0.120 | 0.800 | 31.6 | 25 |

## 6.8 Gender

In some public transport systems, there are high rates of sexual assault which may lead some women to avoid crowded buses. This effect can be tested with the reported attitudes towards crowding. It is also possible that the type of trips, in terms of length, time of day, and purpose vary by gender. As mentioned in the introduction to this chapter, the best way to test the effect of gender absent variation in these other factors would be to build a model. As a preliminary step to inform the model, the differences in behavior of men and women are analyzed and found to be quite similar. Table 6.19 shows that the proportions of males and females with each strategy type are almost identical, and average trip lengths are similar.

**Table 6.19:** Strategies by Gender

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Female | 0.284 | 0.224 | 0.492 | 17.9 | 384 |
| Male | 0.288 | 0.224 | 0.488 | 19.0 | 299 |

## 6.9 Trip Purpose

Some trips require the user to be at their destination at a specific time. Trips to work and school often fall in this category. These trips are also made frequently and passengers with related trip purposes may be sensitive to time savings. In contrast, social and shopping trips are often made more leisurely with less attention to timing. Therefore, trip purpose is expected to have an effect on passengers' route choice strategies. Passengers going to work or school are expected to be more likely to opt to take Route 607, particularly if their trip is long.

In fact, Table 6.20 shows that passengers who are going to school are more likely to wait for a Route 607 bus, but those who travel to work are the least likely to wait for Route 607. However, average trip length also varies with trip purpose. Work trips are on average the shortest of all trip types - averaging just 14.3 minutes on Route 607. Social and recreation trips are considerably longer, lasting an average of 21 minutes on Route 607, and shopping trips are on average 24.4 minutes long.

**Table 6.20:** Strategies by Trip Purpose

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Work/Business | 0.316 | 0.214 | 0.470 | 14.3 | 332 |
| School/Education | 0.280 | 0.160 | 0.560 | 20.0 | 50 |
| Shopping/ Personal | 0.185 | 0.264 | 0.551 | 24.4 | 178 |
| Social/Recreation | 0.312 | 0.215 | 0.473 | 21.0 | 93 |

In order to control for trip length effects, analysis is conducted on a subset of responses with reported trips between 20 and 45 minutes in length, in terms of Route 607 running time. This analysis confirms that with trip length controlled for, individuals on work/business or school/education trips are more likely to wait for Route 607 buses than respondents who were traveling for shopping/personal or social/recreational reasons. Results are summarized in Table **??**

**Table 6.21:** Strategies by Trip Purpose, Controlling for Trip Length

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Trip Length | Sample Size |
|---|---|---|---|---|---|
| Work/Business | 0.100 | 0.175 | 0.725 | 30.8 | 40 |
| School/Education | 0.077 | 0.154 | 0.769 | 30.8 | 13 |
| Shopping/ Personal | 0.151 | 0.189 | 0.660 | 32.0 | 53 |
| Social/Recreation | 0.192 | 0.192 | 0.615 | 32.1 | 26 |

## 6.10 Time of Day

Service frequency for the routes changes at different times of day. This means that the waiting time for each strategy varies by time of day. Time of day variation is also correlated with crowding, as buses are more crowded in peak periods. In addition, trip purpose is likely to vary by the time of the trip. Table 6.22 shows passenger strategies in the different time periods covered in the survey.

**Table 6.22:** Strategies by Time of Day

| | First Bus | Favorite Bus: Route 207 | Favorite Bus: Route 607 | Average Trip Length | Sample Size |
|---|---|---|---|---|---|
| Before 7:00 | 0.227 | 0.386 | 0.386 | 19.1 | 44 |
| 7:00 to 9:00 | 0.355 | 0.192 | 0.453 | 12.7 | 245 |
| 9:00 to 16:00 | 0.233 | 0.195 | 0.572 | 21.9 | 257 |
| 16:00 to 19:00 | 0.248 | 0.200 | 0.552 | 21.1 | 165 |
| After 19:00 | 0.343 | 0.371 | 0.286 | 17.5 | 70 |

Route 607 service begins later and ends earlier than Route 207 service, explaining the low levels of Route 607 preference in these early and late periods. The first Route 207 bus departs Hayes By-Pass at 4:50, while the first Route 607 bus does not depart Uxbridge until 5:29. By 6:00, Route 207 buses have a scheduled headway of seven minutes, while Route 607 begins with a headway of ten minutes. During the AM peak, Route 207 service drops to five minute headways and Route 607 to eight minutes. In the midday, this ratio is similar with Route 207 at six minute headways and Route 607 at ten minutes. In the PM peak, the headways of five minutes and eight minutes for routes 207 and 607, respectively, return. After the PM peak, Route 607 ends service much earlier than Route 207. The last Route 607 bus arrives at the terminal at 21:57, while Route 207 buses run until almost 2:00 AM. As expected, preference for Route 607 after 19:00 is very low.

The preference for Route 607 is higher in the midday period than either peak period. This could be because while the difference in waiting time for the two routes is similar in the peak and midday periods, Route 607 buses are less crowded in the midday, making them more appealing. Crowding is greatest in the AM peak, where the preference for Route 607 is considerably lower than for the midday and PM peak. In summation, low-to-no levels of Route 607 service in early and late periods explain low preference for this route in those periods. In the peak and midday periods, relative levels of service are comparable and differences in behavior are likely due to varied crowding levels.

## 6.11 Consistency of Probabilistic Model and Survey Results

There were four main explanatory factors that were analyzed using both the probabilistic model inferences and survey data. These are: trip length, crowding, use of countdown information, and frequency of corridor use. Table 6.23 summarizes the main findings of each set of analyses for these four factors. The inferences of the probabilistic model and the results of the survey data are consistent in the relationship they finding between trip length and route choice strategies as well as the relationship between access to or use of countdown information and route choice strategies. For crowding and frequency of corridor use, the inferences of the probabilistic model showed a clear impact of these factors on route choice strategy, but the survey results for these factors were inconclusive, likely due to interaction with other factors. The lack of conclusive findings in these two areas may be remedied by further analysis of the survey data, particularly in the form of a model. At this point, however, the consistency of results in the other two areas suggest that both methods of analysis produce viable results.

**Table 6.23:** Comparison of Main Findings of the Probilistic Model and the Survey

| Explanatory Factor | Probabilistic Model Findings | Survey Findings |
|---|---|---|
| Trip length | Longer trips correlated with greater preference for Route 607. | Longer trips correlated with greater preference for Route 607. |
| Crowding | Passengers boarding at crowded stops showed decreased preference for Route 607, particularly for shorter trips. | Inconclusive findings |
| Use of countdown information | Passengers at stops with countdown information are less likely to have a first bus strategy. | Passengers who used countdown information are less likely to have a first bus strategy. |
| Frequency of corridor use | Frequent users are more likely to prefer Route 607. | Inconclusive findings |

## 6.12 Conclusions

The survey collected a wealth of information and this analysis represents the first steps in understanding the general characteristics in route choice behavior. Already, it is clear that a host of factors influence individuals' route choice strategy. To isolate the magnitude of the effect of certain variables, a model would have to be built. However, this analysis reveals some salient factors. First and foremost, as was found by applying the probabilistic model to the Oyster data, trip length is a very strong predictor of route choice strategy. Individual variation in attitudes towards walking and waiting time, as well as levels of risk aversion also appear to have a strong impact on route choice strategy. Crowding, income, and trip purpose are also likely to be important factors, but more analysis is needed to clearly see the effect of these factors in isolation. With regard to crowding, a high degree of individual variation appears to exist in the perception that a bus is too full to board. As the probabilistic model analysis suggested, use of countdown information also affects passengers' route choice strategy.

A few important points from this analysis should be highlighted. First, there is a high degree of consistency in the effects of factors that were inferred from the probabilistic model and the results of this analysis of the survey data. This speaks to the validity of the probabilistic model as well as the online survey. Secondly, the high number of factors that appear to influence route choice strategy, and the fact that many of these factors may be correlated or otherwise interact suggests that a complex model of route choice strategy is needed.

# Chapter 7

# Implications for Service and Network Planning

Previous chapters present several methods to categorize passengers according to their route choice strategy in a multi-route bus corridor. An individual's route choice strategy directly impacts his or her waiting time for a bus. In addition, route choice strategies in aggregate affect passenger loads on vehicles, which in turn affect dwell times at stops, changing in-vehicle time for all passengers. All of these factors - waiting time, crowding levels, and in-vehicle time are common indicators of service quality. This means that a better understanding of passengers' route choice strategies can help planners make better assessments of service quality and more informed decisions about service and network planning.

Analyses in chapters 4 and 6 identify important factors that are strong predictors of individuals' route choice strategies, particularly in the Uxbridge Corridor, where passengers have the option to take limited stop service. This information can also be used to inform service changes and network planning that may alter these factors and in turn change passenger route choice strategies. An understanding of these factors can also help planners identify corridors that are good candidates for limited stop service.

## 7.1 Implications for Local-Only Corridors

In the Beulah Corridor, the dominance of a first bus strategy among the corridor users makes a strong case for headway coordination among parallel bus routes. This corridor also draws attention to the question of route grouping or co-location at stops. When stops for parallel routes are not located in the same place, passengers may prefer not to or be unable to use a first bus strategy, given that they would rather alight at one stop than the other. Due to both of these observations, the main implications drawn for the Beulah Corridor and similar local-only corridors are to introduce corridor-level headway coordination and to co-locate the stops for routes that have many shared passengers.

### 7.1.1 Corridor-Level Headway Coordination

The most significant finding for the Beulah Corridor was the overwhelming dominance of a first bus strategy. This implies that the majority of people who board and alight from a bus where routes 196 and 468 overlap are aware of both options and take whichever arrives first. For these passengers, waiting time is a function of the combined headways for the two routes, rather than the headway for one route exclusively. Having two routes to choose from reduces the waiting time for these individuals relative to people with a favorite bus strategy, by effectively increasing the frequency with which buses arrive at their stop. However, waiting time is a function not only of the headway, but also of the variation in headway, as seen in Equation 7.1.

$$E[V] = \frac{E[H]}{2} + \frac{\sigma_H^2}{2E[H]} = \frac{E[H]}{2}\left(1 + CV^2\right) \tag{7.1}$$

where $V$ is the waiting time, $H$ is the set of headways, $\sigma_H^2$ is the headway variance, and $CV$ is the coefficient of variation of the headways.

In London, bus schedules are set individually for each bus route and each bus route is privately operated on a separate contract. The contract has incentives for the operator to maintain even headways for the individual route. This means that for an individual route, even headways are scheduled and variation is due to operational challenges. When multiple routes are considered together, the combined scheduled headways will not be even because they are the result of two or more separate schedules. This means that when multiple routes are considered together, bunching and uneven headways result in waiting times that are longer than could be achieved with the same number of vehicles if they were operating on a schedule with even combined headways.

The variation in single-route and combined headways can be compared using the coefficient of variation. Coefficients of variation were calculated for the AM peak using the ten weekdays in September and October. In the inbound direction, headways at the Crown Point/ Knight's Bridge stop were analyzed, and in the outbound direction the headways at Norwood Road/ Robson Road were considered. These were the boarding stops used in the empirical analysis of the corridor. Before calculating the coefficients of variation, outliers were removed[1]. The scheduled headways on Route 468 are seven minutes inbound throughout the period and six minutes outbound, and the scheduled headways for Route 196 are eleven minutes in both directions. Table 7.1 shows that combined headways have the largest coefficient of variation: .78 in the inbound direction and .74 in the outbound direction. Route 468 headways are almost as varied, particularly in the inbound direction where the coefficient of variation is .75, while the single-route headways for Route 196 are much less varied, with coefficients of variation of .42 and .44, in the inbound and outbound directions, respectively. This confirms that, particularly in comparison to Route 196, the combined headways are more varied than the same route headways.

The high coefficient of variations of the combined headways suggest that first bus passengers (the vast majority of Beulah Corridor users) could benefit from headway coordination at

[1] Outliers were determined by first calculating the inter-quartile range (IQR) for all headways. The IQR is the 75th percentile value less the 25th percentile value. Any values that were greater than the 75th percentile plus 1.5 times IQR were deemed outliers.

**Table 7.1:** Beulah Headway Variation

| | Inbound | | |
|---|---|---|---|
| | Route 196 | Route 468 | Combined |
| Average Headway | 11.89 | 7.61 | 4.09 |
| Coefficient of Variation | 0.42 | 0.75 | 0.78 |
| Expected Waiting Time | 7.00 | 5.95 | 3.30 |
| | Outbound | | |
| | Route 196 | Route 468 | Combined |
| Average Headway (minutes) | 11.57 | 6.38 | 4.02 |
| Coefficient of Variation | 0.44 | 0.60 | 0.74 |
| Expected Waiting Time (minutes) | 6.91 | 4.35 | 3.12 |

the corridor level. Currently, Route 468 operates at a frequency of ten trips per hour and Route 196 at a frequency of five trips per hour. Maintaining the same overall frequency, the two routes together could provide 15 trips per hour with four minute combined headways. Assuming the scheduled headways are uniform, there will still be some variation due to operation. Ideally, the operation and oversight of the routes would also take place at a corridor level to improve the ability of operators to use real-time control strategies to maintain even combined headways. Under the first scenario, the coefficient of variation is assumed to be .6, while under the second scenario, the coefficient of variation is assumed to be .4. Table 7.2 shows the waiting time improvements that could be made under two different scenarios. Waiting time improvements of 30 to 55 seconds would be experienced by Beulah Corridor users with first bus strategies, under these scenarios.

**Table 7.2:** Beulah Corridor Waiting Time Improvements

| | Current | CV of .6 | CV of .4 |
|---|---|---|---|
| Expected Waiting Time (minutes) | 3.2 | 2.7 | 2.3 |

However, instituting this kind of headway coordination requires changing the headways for the individual routes so that they are equal. Changing the frequency of bus service on an individual route could negatively affect users on other parts of the route, outside the Beulah Corridor. Frequencies are typically set in order to accommodate passengers at the peak load point on a route. Figures 7-1 and 7-2 show the inbound and outbound loads on each route in the AM peak.

On Route 196, loads in the outbound direction are very low and the peak load in the inbound direction is within the Beulah Corridor. On Route 468, the peak load is also in the inbound direction, within the Beulah Corridor. At this point, vehicles have a median load of almost 50 passengers. Route 468 has similarly high loads in the inbound direction at Blanchedowne, five stops after the corridor ends. There are also relatively high loads (median 43 passengers per vehicle) at Cromwell Road and Hogarth Crescent in the outbound direction. Therefore, while the peak load point for Route 468 is in the Beulah Corridor, it is possible that increasing Route 468 headways would negatively affect passengers at these other high load points outside the corridor.

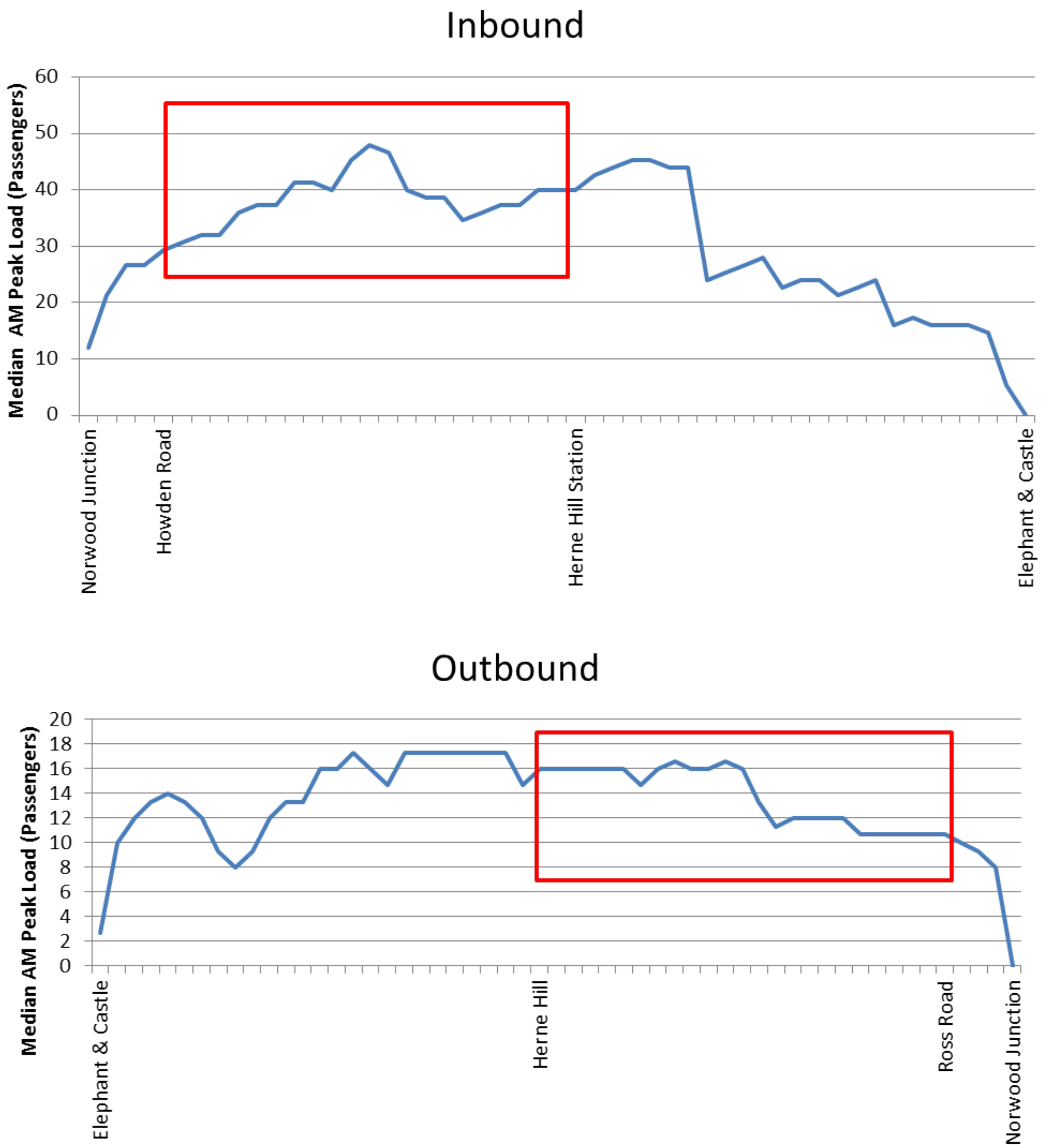
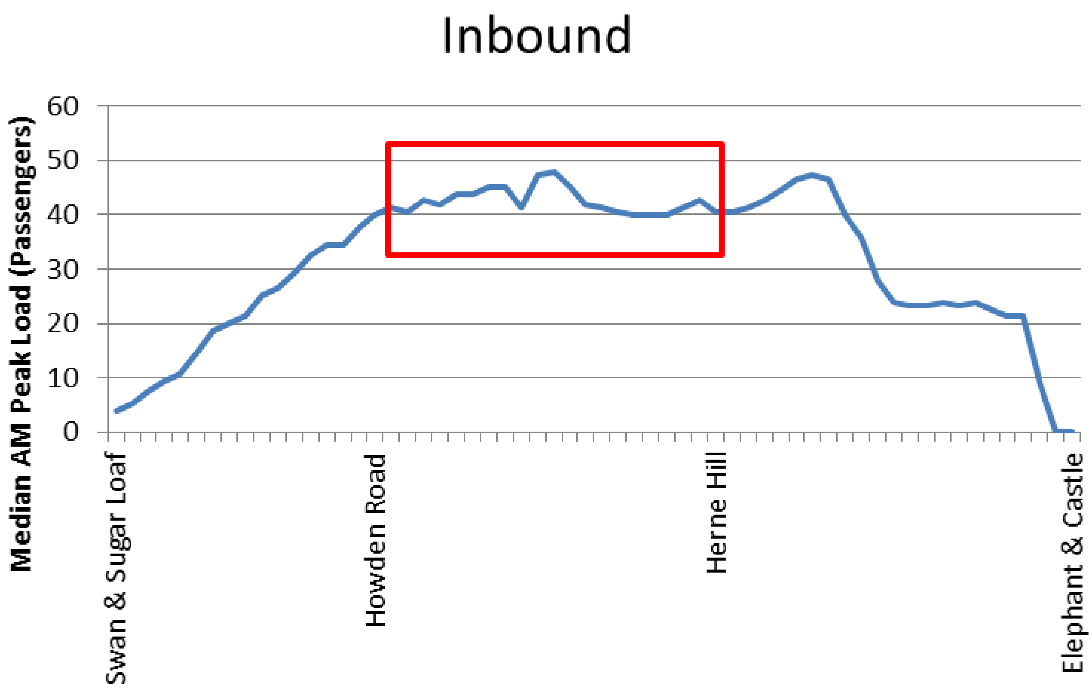



**Figure 7-1:** Route 196 AM Peak Loads

At the network level, overlapping bus routes are so common in London that approximately 40% of of bus trips on the network can be made on multiple bus trips (Sanchez Martinez, 2013). This suggests that there are many opportunities for headway coordination. While in some cases the cost to users outside the corridor will outweigh the benefits to users in the corridor, in others the opposite will be the case. Route choice strategy assessment combined with an assessment of the potential for corridor-level headway coordination can likely identify opportunities for waiting time savings in the London network without requiring additional resources.

In addition to the influence on waiting time, establishing corridor-level headway benchmarks



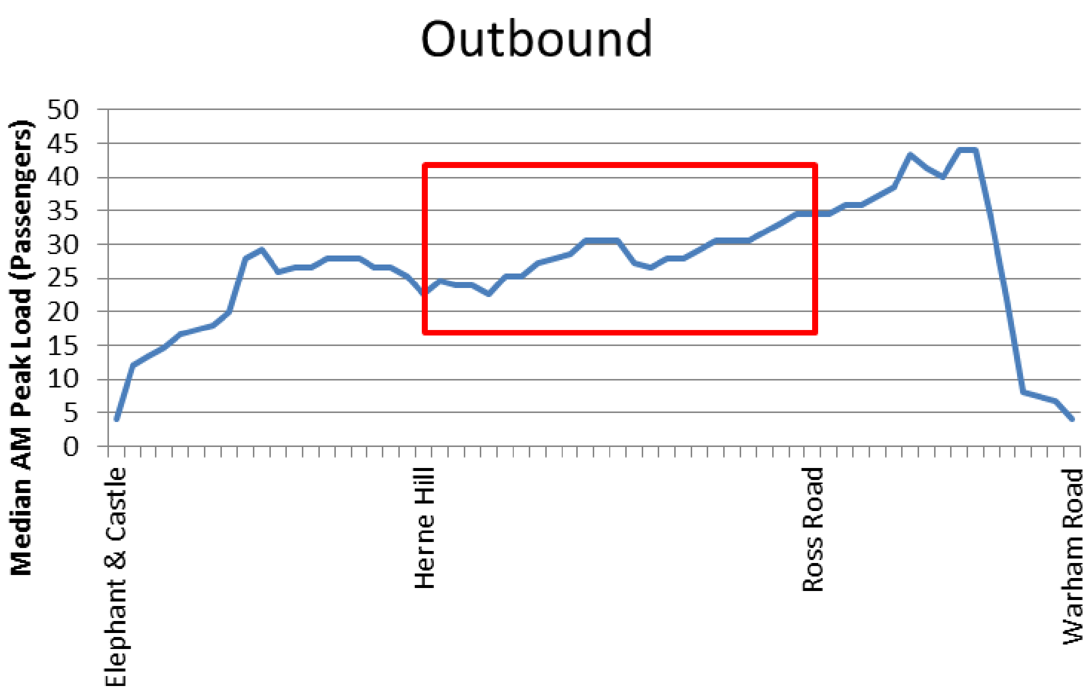




**Figure 7-2:** Route 468 AM Peak Loads

affects load balancing between vehicles and routes. If the two routes have very different loads at the start of the corridor, setting equal frequencies and headways for the two routes will maintain or worsen the uneven loads between the two routes. Instead, lower headways can be set for the less-crowded to attempt to encourage more passengers in the corridor to board it. In the case of the Beulah Corridor, the loads on the two routes are similar at the start of the corridor in each direction. Therefore, setting even headways would help maintain these even loads between routes and between individual vehicles on each route. This improves comfort for passengers and makes it easier for operators to maintain even headways. Crowding was found to be a potential explanation for the favorite bus strategies observed among about 8% of inbound passengers in the AM peak. If loads are more evenly distributed, these passengers will not be faced with as many over-crowded buses that they opt not to board, and it is likely that all passengers will switch to a first bus strategy.

### 7.1.2 Co-locating stops in the shared segment

Another issue observed in the corridor was the presence of a few stops that are geographically offset. There are 734 trips per day made in the corridor that have origins or destinations at the offset stops. The analysis of passengers who board and alight at the offset stops, which was summarized in Chapter 4, revealed that while passengers were somewhat flexible about their selection between the nearby stops, many appeared to favor one stop over the other. For passengers whose destination stops are offset, they can make the choice between waiting for a bus that goes to their preferred stop or taking the first bus. But for passengers who board at stops that are not co-located, there is no option to take the first bus. Stops are too far apart to allow the passengers to wait in between them for either bus route, so these passengers must elect to wait for one route or the other. This means they experience the longer single route waiting times, when they could otherwise have experienced the first bus waiting times.

The message gleaned from the Beulah Corridor behavior is that when stops must be placed in different locations (due to curb constraints at stops served by many routes), one should consider which routes passengers are able to take to the downstream destinations. Whenever possible, routes with the greatest number of potentially-shared passengers should be grouped at the same stop location.

## 7.2 Implications for Corridors with Limited Stop Service

In the Uxbridge Corridor, the presence of limited stop service leads to many passengers opting for a favorite bus strategy. The strong preference for Route 607, the limited stop route, is revealed, in part, by the uneven loads on the three routes in the corridor. These loads and a consideration of the origins and destinations of people on the corridor suggest that service frequencies for Route 607 should be increased. In addition, Route 427, which begins in Uxbridge, could be shortened to end at Ealing Broadway or even before, reducing unnecessary overlap between the two local routes. Like on the Beulah Corridor, passengers on the Uxbridge Corridor could benefit from corridor-level headway coordination. However, due to the limited stop service, coordination on this corridor would be more difficult.

The analysis of the factors that influence strategy choice on the Uxbridge Corridor reveal the importance of information when individuals are able to select between limited stop and local service. They also suggest that corridors that will draw the biggest demand for limited stop service have long trip lengths and a high volume of work and school trips.

### 7.2.1 Implications of Load and OD Analysis

Even without strategy analysis, a simple load analysis of the Uxbridge Corridor shows potential for service improvements through reallocation of resources. Figure 7-3 shows the dramatic difference in the median number of passengers on inbound Route 607 buses from the number on the local route buses in the AM peak. In the most crowded portion of the corridor, loads on Route 607 are double the loads on the local buses. In addition, the loads on Route 427 trail off after Leeland Road, and are very low after Ealing Broadway.

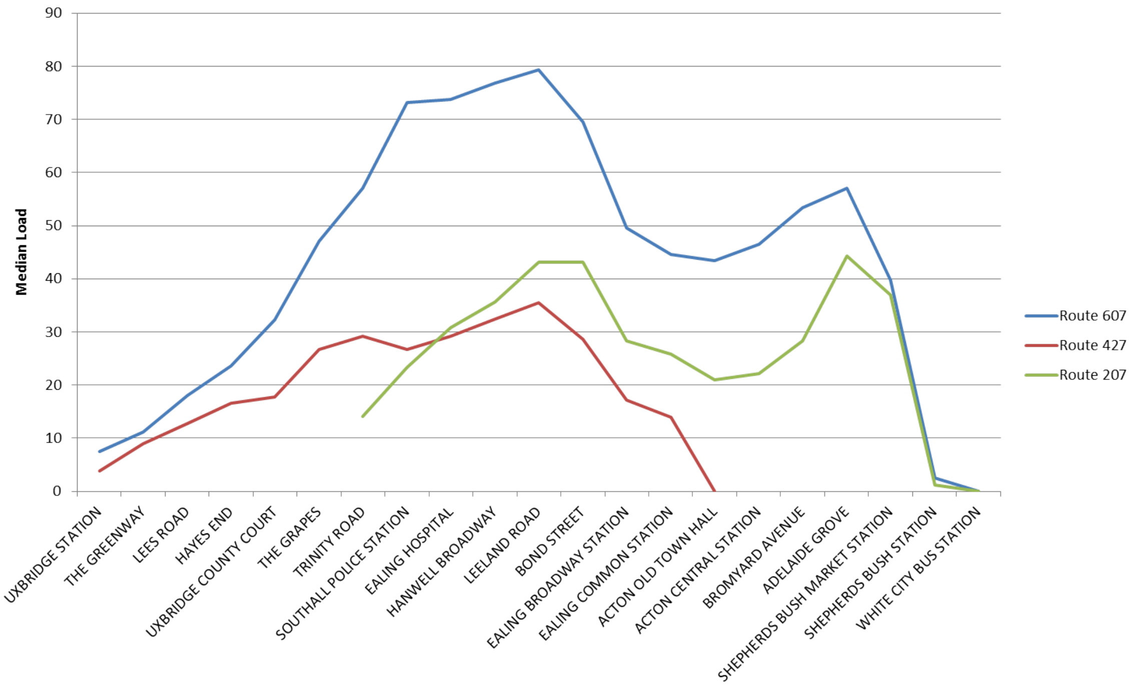



**Figure 7-3:** Uxbridge Corridor Loads

These loads suggest that crowding on Route 607 could be alleviated by re-allocating buses from the local routes to the limited stop routes. The drop off in Route 427 loads also reveals an opportunity to have Route 427 buses turn around sooner, reducing the number of vehicles needed on Route 427, and making them available for use on Route 607. Crowding was revealed to be a significant factor dissuading passengers from waiting for Route 607 buses. With more vehicles allocated to Route 607, crowding would be at least temporarily reduced. However, the re-allocation of resources to Route 607 will make waiting for Route 607 buses more appealing due to shorter headways and less crowding. More people may shift to a strategy of waiting for Route 607, bringing crowding levels up again, despite the more frequent service. At that point, the need for re-allocation to Route 607 should be re-evaluated.

Any evaluation of the re-allocation of resources to the limited stop route should include consideration of the level of service that is desired at local-only stops. 53% of trips on the corridor have their origin, destination, or both at a local-only stop. If vehicles are shifted to Route 607 service, this proportion will likely decrease as more people find it worth it to board and alight at combined stops, but some people will continue to prefer local-only stops due to strong distaste for walking. A minimum level of service should be set as a lower bound on the number of vehicles that should be allocated to the local routes.

Shortening Route 427 to end at Ealing Broadway could be done with minimal affect on passengers. Of the approximately 92,500 trips made daily on the corridor, only 87 trips would be affected. These consist of trips that are served only by Route 427 and have destinations beyond Ealing Broadway in the inbound direction or originate before Ealing Broadway in the outbound direction.

During the AM peak, the portion of the route from Ealing Broadway to the end of the route at Acton Old Town Hall takes about 8 minutes in the inbound direction, and the beginning of the outbound trip from Acton Old Town Hall to Ealing Broadway takes about 13 minutes in the AM peak. This means that shortening Route 427 to run from Uxbridge to Ealing Broadway would reduce the cycle time for the route by about 21 minutes. The total cycle time for Route 427 in the AM peak is currently about 154 minutes. With an appropriate reduction in layover time, turning Route 427 buses at Ealing Broadway would shorten the cycle time to 129 minutes. This allows Route 427 to be operated with three fewer vehicles, which can be reallocated to Route 607. Table 7.3 summarizes the proposed changes. Allocating three additional vehicles to Route 607 allows the headway to be reduced to eight minutes. The current median AM peak load on Route 607 buses is 80 passengers at the peak point. Assuming no change in the demand for Route 607, reducing the headway to eight minutes would reduce this load to 71 passengers. In fact, passengers will likely shift to Route 607 if the service is increased. A more dramatic scheme, such as removing Route 427 and extending Route 207 out to Uxbridge, thus removing the overlapping local routes, may be even more effective in that it could free up more resources for Route 607 and better alleviate the crowding on that route.

**Table 7.3:** Proposed Shortening of Route 427

| Route 427 | | | |
|---|---|---|---|
| | Cycle Time | Headway | Number of Vehicles |
| Current | 154 | 8 | 20 |
| Proposed | 129 | 8 | 17 |
| **Route 607** | | | |
| | Cycle Time | Headway | Number of Vehicles |
| Current | 186 | 9 | 21 |
| Proposed | 186 | 8 | 24 |

### 7.2.2 Corridor-Level Headway Coordination

Like in the Beulah Corridor, the Uxbridge Corridor shows a higher level of variability for combined headways than for single-route headways. Analysis of inbound AM peak headways at Southall Police Station shows that headways for routes 207, 427, and 607 have coefficients of variation of just .46, .44, and .44, respectively, while the combined headways for the two routes have a coefficient of variation of .65 (see Table 7.4). When considering all three routes together, the combined headways become even more irregular with a coefficient of variation of .81.

**Table 7.4:** Uxbridge Headway Variation

| | Route 207 | Route 427 | Route 607 | 207/607 Combined | 3-Route Combined |
|---|---|---|---|---|---|
| Average Headway | 4.86 | 7.84 | 8.85 | 3.08 | 2.19 |
| Coefficient of Variation | 0.46 | 0.44 | 0.44 | 0.65 | 0.81 |
| Expected Waiting Time | 2.93 | 4.67 | 5.27 | 2.17 | 1.82 |

As mentioned previously, the expected waiting time for an individual with an unplanned arrival at a stop is a function of the average headway as well as the coefficient of variation. In the Uxbridge Corridor, all three routes have the same operator, but each route has its own contract and each route is scheduled separately without an attempt to coordinate schedules. While the first bus strategy is not as dominant on the Uxbridge Corridor as it is on the Beulah Corridor, the Uxbridge Corridor has a very high volume of passengers, particularly at the combined stops. About 43,700 trips every weekday are made between stops served by Route 607 as well as one or both of the local routes. According to the inferences from the probabilistic model, about 61% of these trips are made with a first bus strategy. These passengers would benefit from more even combined headways. Two target coefficients of variation are set at .6 and .4 for coordinated combined headways. Table 7.5 summarizes the reductions in waiting time that would be expected under these scenarios. If the coefficient of variation could be reduced to .4, this would provide waiting time savings of up to 30 seconds. If the coefficient of variation remains closer to its current level, the savings are smaller.

**Table 7.5:** Potential Uxbridge Corridor Waiting Time Under Coordination

| Expected Waiting Time (minutes) | Current | CV of .6 | CV of .4 |
|---|---|---|---|
| 207/ 607 | 2.17 | 2.0 | 1.7 |
| 3-Route | 1.82 | 1.4 | 1.2 |

However, introducing coordination in the corridor is challenging due to the presence of limited stop service. Because Route 607 skips stops, setting a schedule with even headways between Route 607 and the local routes is nearly impossible. However, coordination could be achieved between the two local routes. In addition, it may be possible to design a schedule that has even headways between the limited stop and local route(s) at specific stops, selected because they have a high number of boardings.

### 7.2.3 Rationality, Risk, and Information

The survey questions about passenger attitudes revealed that bus users were more willing to take the risk of waiting for a faster bus when they had access to information about future arrivals. This was confirmed by the fact that at stops with countdown information, the probabilistic model inferred a greater proportion of passengers waiting for Route 607. Similarly, those people who reported using countdown information in the survey were more likely to prefer Route 607 and less likely to take the first bus.

The correlation between a preference for Route 607 and the use of countdown information was found regardless trip length, which is interesting given the variation in expected travel time savings. Table 7.6 shows the expected AM peak waiting times and median in-vehicle times, based on AVL data, for each of the inbound sample OD pairs used in the empirical and probabilistic analysis. These OD pairs all begin at the same boarding stop, Southall Police Station, and each sample includes a specific destination stop or stops. The first bus strategy is fastest for Sample 1, a short trip of about 15 minutes. The two strategies are almost equivalent for Sample 2, which is a slightly longer trip of about 24 minutes. Waiting for Route 607 is the faster option for samples 3 or 4, which are longer trips. This means that a rational actor who has no information about arrivals should take the first bus if he or she is making a short trip, like that of Sample 1, but should wait for Route 607 for longer trips, assuming the individual value waiting and in-vehicle time equally. In fact, these values vary from person-to-person, and usually are not equal.

**Table 7.6:** Waiting and In-Vehicle Times by Strategy for the Inbound Samples

| | First Bus Strategy | | | Favorite Bus: Route 607 | | |
|---|---|---|---|---|---|---|
| | Waiting Time | In-Vehicle Time | Total | Waiting Time | In-Vehicle Time | Total |
| Sample 1 | 1.8 | 13.2 | 15.0 | 5.3 | 11.2 | 16.5 |
| Sample 2 | 1.8 | 22.2 | 24.0 | 5.3 | 18.9 | 24.2 |
| Sample 3 | 2.2 | 36.9 | 39.1 | 5.3 | 32.0 | 37.3 |
| Sample 4 | 2.2 | 53.7 | 55.9 | 5.3 | 46.7 | 52.0 |

In addition, when passengers have access to information, they can make more informed decisions. While on average, waiting for a Route 607 bus is not worthwhile for the short trip in Sample 1, if an individual knows a Route 607 bus is arriving in just two minutes, it would be worth it to wait for it. This means that, in theory, access to information about bus arrivals allows passengers to make more rational decisions, according to their personal values of time. In practice, it is impossible to test the rationality of passengers' decisions without knowing the time at which individuals arrived at the bus stop. However, the fact that individuals who used countdown information behaved differently from individuals who did not suggests that they are incorporating the information into their decision-making process.

Countdown bus arrival information provides passengers with estimates of their waiting time, but passengers must estimate the difference in in-vehicle time for the limited stop and local service. This may be difficult. The fact that individuals alter their behavior when given information about bus arrivals suggests that the same may be true if they were given real-time predictions of in-vehicle time for different options. A mobile phone application that informs passengers not only of bus arrivals at their stop, but also of the predicted arrival time at their destination could significantly improve the passenger experience. The same effect could possibly be achieved by posting the predicted arrival times of buses at major destination stops on countdown signs. These information sources would enable more informed, and presumably more rational choices.

### 7.2.4 Factors that Influence Strategy Choice

Both the inferences of the probabilistic model and the survey results uncovered correlations between certain factors and passenger strategies. Knowledge of these factors can help network planners identify other corridors where passengers would be likely to show a strong preference for limited stop service.

Trip length was found to be the strongest predictor of passenger route choice strategy. Passengers making longer trips are more likely to wait for a Route 607 bus. Corridors where a high volume of passengers make long trips are ideal for limited stop service.

Crowding is also a significant mitigating factor in passengers' route selection. Passengers are less likely to wait for Route 607 buses at stops and in periods when these buses are very full. Some passengers will wait specifically for local buses that are less crowded. Network planners should expect interaction between crowding levels, service frequency, and passenger route choice strategies.

Frequent users of the Uxbridge Corridor were found to be more time sensitive and less crowding sensitive, according to the inferences of the probabilistic model. This suggests corridors with many frequent users could benefit from limited stop service, as these frequent users value the time savings that limited stop service offers.

As discussed in Section 7.2.3, information affects passengers' route choice strategies. Providing passengers with information about bus arrivals will make them more likely to wait for limited stop service. Therefore, countdown signs are very important at stops served by limited stop and local service. In general, when passengers' choice sets are expanded, information allows the passengers to make better decisions, taking advantage of their options to minimize travel time.

The survey assessed passenger attitudes through a series of statements that respondents rated. The responses to these statements revealed that passengers have a wide variety of attitudes toward crowding, risk, waiting, and walking time. In addition, their strategies are correlated with these attitudes. This implies that planners should expect a large degree of individual variation in response to attributes of the corridor such as vehicle loads, stop spacing, and service frequency. The responses also confirmed that passengers are much more willing to take the risk of waiting for a faster bus when this risk is diminished by information about future bus arrivals.

For long trips, people in the highest income bracket (making more than £50,000 per year) were more likely to wait for Route 607 buses, suggesting they may have a higher value of time. However, using income to select corridors for limited stop service would raise legitimate equity concerns.

Trip purpose appears to play some role in strategy choice. Passengers going to school or work are more likely to prefer Route 607. This suggests that corridors with a large portion of school and work trips are better candidates for limited stop service. The other reason these types of trips are ideal for limited stop service is that their destinations are usually more concentrated. Places of work are often concentrated in business districts and schools generate a large amount of demand at a specific location and time. Because limited stop service, by definition, cannot serve all origins and destinations, corridors with demand concentrated at certain locations are better candidates for limited stop service.

## 7.3 Conclusions

The strategy analysis on both corridors reveals that substantial waiting time savings can be achieved through headway coordination at the corridor level. It is also speaks to the importance of co-locating stops for routes with shared ridership.

For the Uxbridge Corridor, specifically, definitive load imbalances and the popularity of the limited stop service suggest that the current allocation of resources between the three routes is not optimal. This speaks to a broader interaction between service frequency, crowding, and passenger route choice strategies that planners must expect whenever introducing limited stop service to a corridor. In terms of general planning, the analysis of the factors that are correlated with strategy choice reveal that limited stop service should be introduced in corridors with long trip lengths and a high volume of work and school trips. Planners should expect a high variability in individual behavior in corridors with overlapping limited stop and local service. Finally, crowding and access to real-time information should be expected to heavily influence passenger route choice behavior.

# Chapter 8

# Conclusion

Given the prevalence of multi-route bus corridors in London and in cities globally, developing a better understanding of how passengers select routes within these corridors can provide important insight in the passenger experience and inform planning decisions. This thesis improves the understanding of passenger behavior in multi-route corridors in several ways. First, it provides three methodologies for the analysis and characterization of passenger behavior in a multi-route corridor based on AVL and AFC data. Second, the research designed and administered a web-based survey of passengers on the Uxbridge Corridor that collected information on their route choice strategy and many other factors that may influence passenger behavior. Based on inferences from AVL and AFC data and the data collected in the survey, this thesis discusses several explanatory factors that affect passengers' route choice strategies. In addition, analysis of the representativeness and validity of the survey documents the viability of web-based surveys for collecting detailed information from a large number of public transportation users. Finally, this thesis connects the understanding of route choice strategy and passenger behavior in a multi-route corridor to network and service planning decisions by making recommendations for the corridors analyzed and more generally for multi-route corridors.

## 8.1 Identifying Route Choice Strategies from AVL and AFC Data

Three methods for the analysis of AVL and AFC data to understand passenger behavior are proposed. The first is an empirical analysis, which compares the expected proportions of passengers who would take each route according to actual bus arrival information and assuming that all passengers board the first bus to arrive that serves their destination to the actual proportions of passengers on each route. Through this analysis, the dominance of a first bus strategy on the Beulah Corridor, and the deviation from a first bus strategy on the Uxbridge Corridor was identified.

The second method discussed is a probabilistic model that estimates the proportion of passengers with first bus and favorite bus route choice strategies based on the headways that preceded each bus boarding. The predictions of this model were applied to samples in both corridors to compare the predicted demand allocation to the actual proportions of passengers on each route. While the model tended to underestimate demand for the limited stop route, Route 607, on the Uxbridge Corridor, the predictions of the probabilistic model were far more accurate than assuming passengers board the first bus that serves their destination. The probabilistic model was applied to segmented data from each corridor to begin to understand the factors that influence passengers' route choice strategies. In the Beulah Corridor, passengers in the inbound direction were less likely to use first bus strategies, probably due to more crowding on inbound buses than outbound buses. On the Uxbridge Corridor, trip length was the most significant factor influencing behavior, with passengers making longer trips more likely to prefer Route 607. Crowding, frequency of corridor use, and information also affected behavior. Those passengers who boarded the Uxbridge Corridor at stops where the Route 607 buses were particularly crowded showed a decreased preference for Route 607, particularly for shorter trips. The sensitivity to crowded buses appeared to be greater for infrequent users of the corridor than for frequent users. Overall, frequent users show more of a desire for the time savings that come with using a Route 607 bus. Finally, access to bus arrival information in the form of countdown signs appeared to make passengers more willing to wait for a preferred bus.

The final method discussed for understanding passenger behavior from AVL and AFC data is a panel analysis that considers the behavior of individuals who have multiple trips on the corridor over time. This offers a look at the variation of individual's behavior in terms of both route choice and stop choice. Inflexibility in either of these regards suggests that the passenger has a preferred route or stop. In the Beulah Corridor a high degree of flexibility in route choice confirms the dominance of a first bus strategy among corridor users. On the Uxbridge Corridor, many users repeatedly selected Route 607 buses, confirming the preference for the route among many Uxbridge Corridor passengers. The analysis of stop variation showed some flexibility, but also some preferences for specific stops on both corridors.

The results of the three methods confirm that a lot of information on passenger behavior can be inferred from AVL and AFC data. Planners can apply these methods to multi-route corridors to judge the quality of service on the corridors, particularly in terms of passenger waiting time and in-vehicle time. They can also use the results of these analyses to inform planning decisions regarding the corridor.

## 8.2 Improving Understanding of Passenger Behavior from a Web-Based Survey

The web-based survey asked respondents to report details about two recent trips that they took on the Uxbridge Corridor. More than 9,000 people (an 18% response rate) responded to the survey, and they provided complete, valid information for about 4,505 trips. In addition to information about their recent trips, they responded to statements about their attitudes towards crowding, waiting time, in-vehicle time, walking time, and their levels of risk aversion, and level of trust in countdown information. Finally, the individuals responded to basic demographic questions about their age, income, gender, and whether or not they have any disabilities that affect their experience as a bus passenger.

The web-based survey proved to be a viable way to collect a large amount of information from a large sample of individuals at very low cost. A few issues with the representativeness of the responses were identified. Elderly and disabled passengers were under-represented due to the fact that they are less likely to provide TfL with an email address. This bias could be overcome with targeted paper surveys mailed to these individuals. Respondents were more likely to report trips they took on Route 607 and less likely to report trips they took on Route 427. Regardless of route, they were more likely to report longer trips. This could be addressed by providing users with a summary of their recent Oyster card activity on the corridor so that they can remember which route they took and do not forget or disregard shorter trips. Some users appear to have been confused by certain questions, and there was some amount of incompleteness likely due to a combination of survey fatigue and passengers failing to remember certain details. However, the benefit of an online survey is that due to the large volumes of data that can be collected, even with incomplete or questionable responses discarded, large sample sizes remain.

Analysis of the sample data revealed that many factors influence passenger behavior on the Uxbridge Corridor. As the analysis of AFC and AVL data inferred, trip length was found to be highly correlated with a preference for the limited stop service route, Route 607. Respondents' attitudes towards crowding, walking and waiting time and their levels of risk aversion were also strong predictors of their route choice strategies. Crowding averse people tend to opt for less-crowded local buses when boarding at stops where Route 607 buses are especially crowded. Respondents who reported a strong aversion to waiting time were less likely to wait for Route 607 buses. Those who expressed a dislike of walking were more likely to board at a local stop. Passengers who are more risk averse are more likely to take the first bus, rather than waiting for a specific bus route.

Respondents also showed a clear connection between their use of countdown information and their decision to wait for a particular bus route. Those who used countdown information were less likely to have a first bus strategy. Crowding, income, and trip purpose are also likely to be important influences of route choice behavior. Due to correlations between these factors and other influences more analysis is needed to clearly see the effect of these factors in isolation.The analysis of these influential factors and their correlations with the route choice strategies reported forms a foundation that can be used to inform the structure of a model that estimates route choice strategy based on a set of explanatory factors and conditions. Such a model can be used subsequently for prediction of response to network and service changes, and evaluation of trade-offs between factors such as walking, waiting, and in-vehicle time.

## 8.3 Implications of the Strategy Analysis

Given the prevalence of a first bus strategy on the Beulah Corridor, and the high volume of overall passengers, including many with first bus strategies on the Uxbridge Corridor, there is a potential benefit of planning vehicle schedules and controlling operation at a corridor level. Currently, because each route is scheduled and operated in isolation, passengers who are able to board multiple bus routes experience uneven combined headways. If schedules can be set at the corridor level, equalizing headways between multiple routes, waiting time can be reduced for those individuals who have first bus strategies. On the Uxbridge Corridor, maintaining even headways between limited stop service and local service is likely impossible, but the headways of the two local routes could be equalized, or headway coordination at specific stops can be attempted.

The existence of stops within the corridor that are not shared between the corridor routes, but rather are located a block or more apart, prevent individuals who board at these stops and alight at other stops in the corridor from using a first bus strategy and benefiting from a shorter waiting time. These shared boardings should be taken into consideration when deciding where to locate stops for specific routes.

Load imbalances between the routes on the Uxbridge Corridor suggest that the current allocation of vehicles between the local and limited stop routes is not optimal. This corridor stands to benefit from a reduction in local service, particularly in the middle portion of the corridor and an increase in limited stop service. Planners should be aware of the expected interaction between service frequency, crowding, and passenger route choice strategies when changing service frequencies on the corridor.

When considering the implementation of limited stop service, more generally, the findings of the thesis suggest that a strong preference for limited stop service is likely to be found on corridors with long trip lengths and a high volume of work and school trips. Providing countdown information on a corridor along with the introduction of limited stop service will likely increase the demand for the limited stop route.

## 8.4 Future Research

There are several ways to extend this analysis and deepen the understanding of passenger behavior on multi-route corridors.

First, this analysis focuses mainly on the decision passengers make about which bus route to board, once they are already at a stop. Only broad consideration was given to the analysis of passengers' decision of which stop to board at. Much information can be gleaned from the automated data, looking at boarding stop selection at the population and an individual level. Boarding stops can be linked to individuals' home postcodes, when provided, or to overall levels of population density around stops. The web-based survey also provides data on the starting and ending location of passenger journeys that allows for the calculation of access and egress time to the stops the individuals boarded and alighted at. These distances can shed light on passengers' stop choice decisions. The data could also be included in a model to asses the trade-offs between access, egress, waiting, and in-vehicle time. This would also allow for the consideration of travel time savings by strategy choice, rather than simply looking at overall trip length.

More broadly, as was discussed in Chapter 6, understanding the magnitudes of the effects of specific factors on route choice strategies can best be accomplished through the development of a model of route choice strategy that includes not only the travel time components, but also the attitude indicators, demographic information, crowding levels, time of day, trip purpose, and use of countdown information. Developing this model requires the development of a comprehensive framework that incorporates all aspects of the decision process, in light of the various factors that affect it.

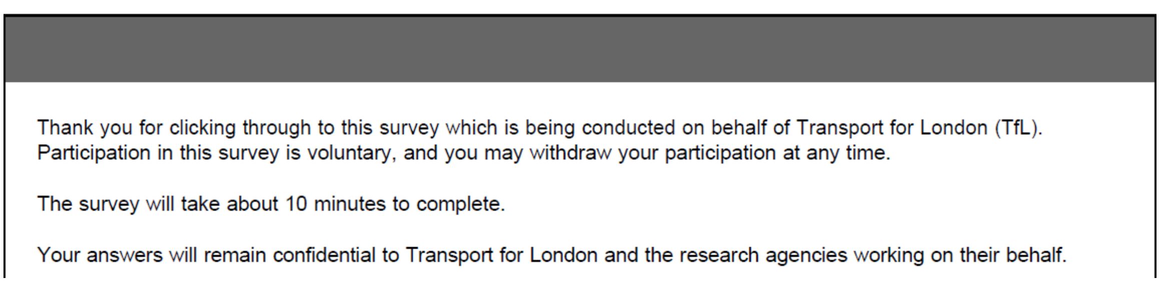
The survey data provides a wealth of information that is not limited to route choice strategies. The correlations between attitudes, trip characteristics, and demographic factors can be further analyzed. The survey also includes detailed information about the use of countdown information. This can be correlated with attitude and demographic information as well. Passenger information is a rapidly changing feature of the bus passenger experience. There is much work to be done in understanding how passengers use information, what information is most useful, and how this affects passenger experience.

The type of strategy analysis employed in this thesis could also be adapted and applied to other route choice decisions including the selection between trips with different transfer points or between different multi-modal options.

Another set of future work focuses on the network and service planning implications. More research is needed to understand how strategies and demand at the bus route level are affected by specific service changes. A set of service configurations and frequencies could be analyzed. This could include the consideration of options other than limited stop, such as zonal service. Analysis of specific corridor-level headway coordination plans could be done at a corridor level with consideration of network-wide implications. In addition, a methodology for the identification of corridors within a network that present the greatest opportunity for corridor-level coordination efforts could be developed.

# Appendix A

# Appendix



Thank you for clicking through to this survey which is being conducted on behalf of Transport for London (TfL).
Participation in this survey is voluntary, and you may withdraw your participation at any time.

The survey will take about 10 minutes to complete.

Your answers will remain confidential to Transport for London and the research agencies working on their behalf.

**Figure A-1:** Introduction to the Survey

Please consider the following statements, and rate them on a scale from strongly disagree to strongly agree.

**1. I will only board a bus if I can get a seat.**

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**2. I will try to squeeze onto a bus even if the bus appears very full.**

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**3. If I don't know when each bus will arrive, I will take the first bus that arrives at my stop, even if a faster bus serves my destination.**

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**4. If I know a faster bus will arrive soon, I will wait for it, even if a slower bus is at my stop.**

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**5. I don't mind walking longer distances to reach a stop served by faster buses.**

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**6. Countdown information often indicates that buses will arrive sooner than they actually do.**

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**7. I prefer spending longer on a bus if it means spending less time waiting at a stop.**

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**8. If a bus is very crowded, I will wait for a less crowded bus.**

| Strongly disagree | Disagree | Neither agree nor disagree | Agree | Strongly agree |
|---|---|---|---|---|
| ○ | ○ | ○ | ○ | ○ |

**Figure A-2:** Attitude Ranking Statements

**9. Have you used any of the following bus routes in the the last two weeks? Please select all routes that you have used.**

- [ ] 196
- [ ] 207
- [ ] 249
- [ ] 427
- [ ] 468
- [ ] 607
- [ ] I have not used any of these routes.

**Figure A-3:** Lead In Question

**You will be asked about two one-way trips, one from home and one from somewhere other than home.**

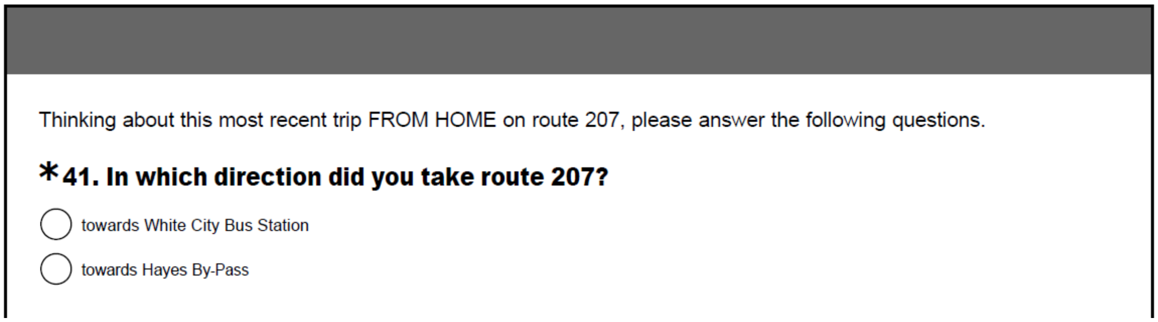
**First, please tell us only about your one-way trip FROM HOME. Think of the most recent time you used routes 207, 427, and/or 607 on a trip from your home, and answer the following questions.**

Questions with an asterisk (*) require an answer in order to continue with the survey.

*** 10. Which of the following best describes your most recent trip FROM HOME on routes 207, 427, and/or 607?**

- ○ I took route 207 only.
- ○ I took route 427 only.
- ○ I took route 607 only.
- ○ I took both routes 207 and 607 to reach my destination, changing from one bus to the other at a stop served by both routes.
- ○ I took both routes 427 and 607 to reach my destination, changing from one bus to the other at a stop served by both routes.
- ○ I did not take any of these routes on a journey from my home in the last two weeks.

**Figure A-4:** Route Identification Question for Home-based Trip

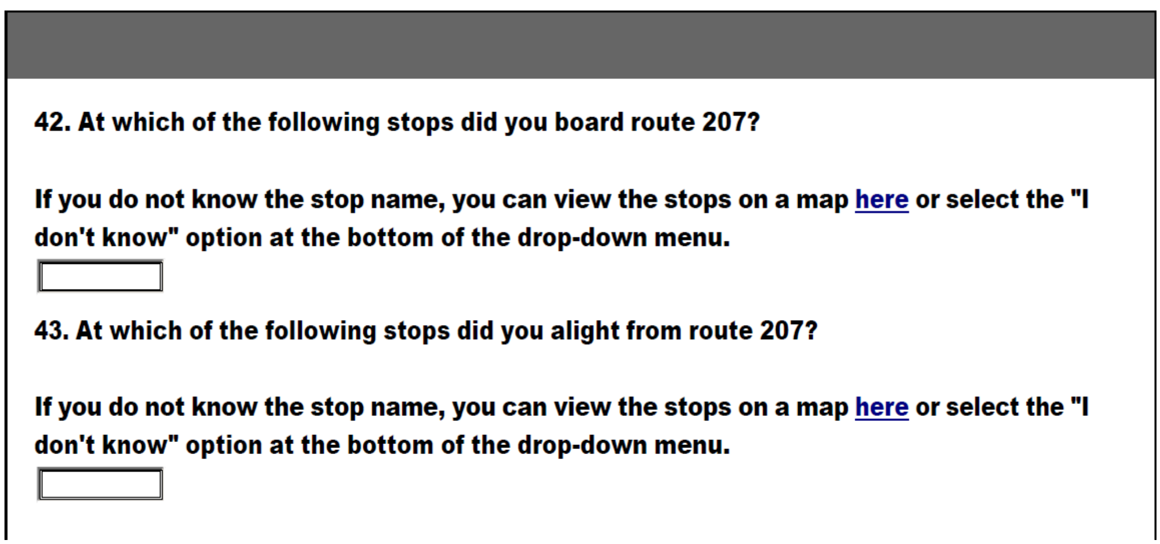


Thinking about this most recent trip FROM HOME on route 207, please answer the following questions.

***41. In which direction did you take route 207?**

- towards White City Bus Station
- towards Hayes By-Pass

**Figure A-5:** Direction Question



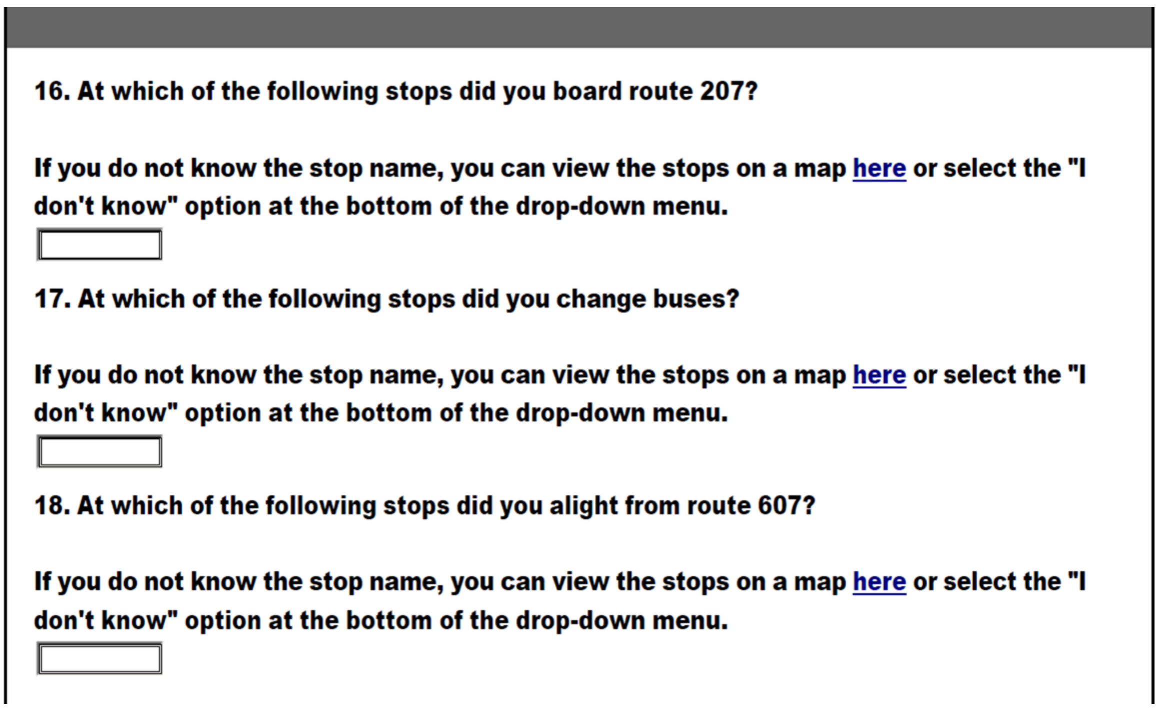
**42. At which of the following stops did you board route 207?**

**If you do not know the stop name, you can view the stops on a map here or select the "I don't know" option at the bottom of the drop-down menu.**

**43. At which of the following stops did you alight from route 207?**

**If you do not know the stop name, you can view the stops on a map here or select the "I don't know" option at the bottom of the drop-down menu.**

**Figure A-6:** Stop Selection Questions for Single Route Option



16. At which of the following stops did you board route 207?

If you do not know the stop name, you can view the stops on a map here or select the "I don't know" option at the bottom of the drop-down menu.

17. At which of the following stops did you change buses?

If you do not know the stop name, you can view the stops on a map here or select the "I don't know" option at the bottom of the drop-down menu.

18. At which of the following stops did you alight from route 607?

If you do not know the stop name, you can view the stops on a map here or select the "I don't know" option at the bottom of the drop-down menu.

**Figure A-7:** Stop Selection Questions for Transfer Option

Thinking about this most recent journey FROM HOME on routes 207, 427, and/or 607, please answer the following questions.

**56. On which day was this journey?**

**Please select from the dropdown menu. If you do not remember, select "I do not remember."**

**57. At what time of day did you begin this journey?**

**Please select from the dropdown menu. If you do not remember, select "I do not remember."**

**58. What is the postcode of the place where you began this journey? Please enter the full postcode.**

Postcode

**59. How did you get to where you boarded the bus?**

- Walk
- Cycle
- Another bus
- Other public transport, including National Rail, London Overground and London Underground

Other (please specify)

**Figure A-8:** Detailed Questions About Origin of Home-Based Trip

**60. At what street/location did you finish this journey?**

Street

Locality/Town

Postcode

**61. Thinking of the place where you ended your journey, why were you there?**

- ◯ Work/Business
- ◯ School/Education
- ◯ Shopping/Personal
- ◯ Social/Recreation
- ◯ Picking up/Dropping off Someone

Other (please specify)

**62. How did you continue your journey after alighting from the bus?**

- ◯ Walk
- ◯ Cycle
- ◯ Another bus
- ◯ Other public transport, including National Rail, London Overground and London Underground

Other (please specify)

**Figure A-9:** Detailed Questions About Destination of Home-Based Trip

Countdown information refers to information indicating how many minutes until a bus will arrive at a stop.

**63. Did you use countdown information on your phone or another device to decide at which stop to board the bus?**

- ◯ Yes
- ◯ No

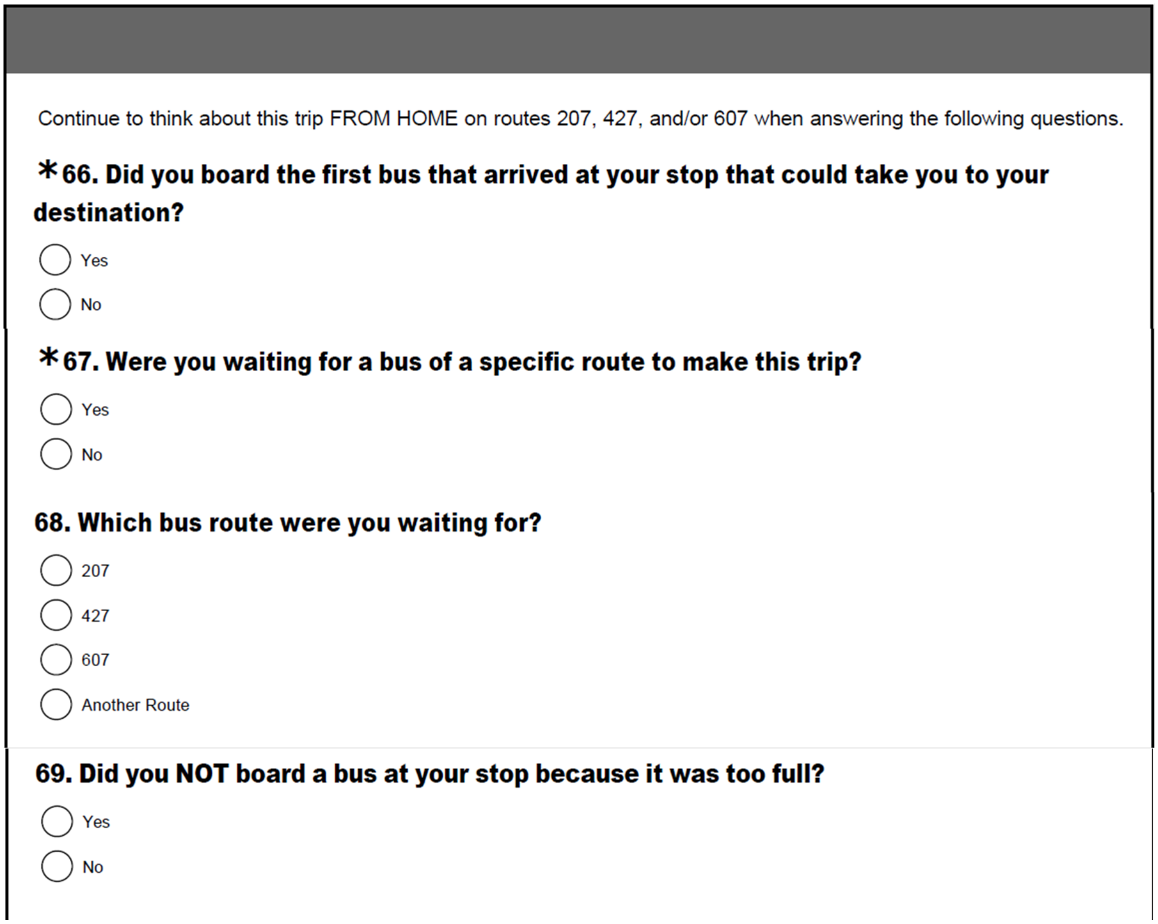
***64. Once at your boarding stop, did you use this information (on your phone, on another device, or on a countdown sign) to decide which bus to board?**

- ◯ Yes
- ◯ No

**65. When you arrived at your boarding stop, the countdown information indicated how many minutes until the bus you boarded would arrive?**

**Please select from the drop-down menu.**

**Figure A-10:** Questions About Use of Countdown Information



Continue to think about this trip FROM HOME on routes 207, 427, and/or 607 when answering the following questions.

***66. Did you board the first bus that arrived at your stop that could take you to your destination?**

◯ Yes

◯ No

***67. Were you waiting for a bus of a specific route to make this trip?**

◯ Yes

◯ No

**68. Which bus route were you waiting for?**

◯ 207

◯ 427

◯ 607

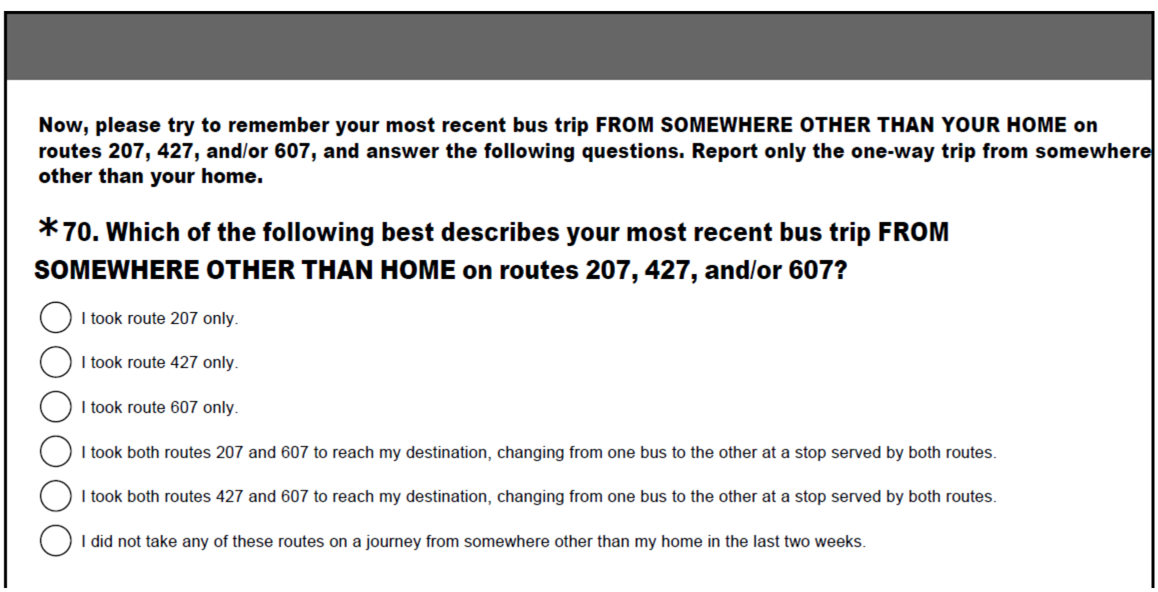
◯ Another Route

**69. Did you NOT board a bus at your stop because it was too full?**

◯ Yes

◯ No

**Figure A-11:** Strategy Identification Questions



**Now, please try to remember your most recent bus trip FROM SOMEWHERE OTHER THAN YOUR HOME on routes 207, 427, and/or 607, and answer the following questions. Report only the one-way trip from somewhere other than your home.**

***70. Which of the following best describes your most recent bus trip FROM SOMEWHERE OTHER THAN HOME on routes 207, 427, and/or 607?**

◯ I took route 207 only.

◯ I took route 427 only.

◯ I took route 607 only.

◯ I took both routes 207 and 607 to reach my destination, changing from one bus to the other at a stop served by both routes.

◯ I took both routes 427 and 607 to reach my destination, changing from one bus to the other at a stop served by both routes.

◯ I did not take any of these routes on a journey from somewhere other than my home in the last two weeks.

**Figure A-12:** Route Identification for Trip from Somewhere Other Than Home

Thinking about this most recent journey FROM SOMEWHERE OTHER THAN HOME on routes 207, 427, and/or 607, please answer the following questions.

**116. On which day was this journey?**

**Please select from the dropdown menu. If you do not remember, select "I do not remember."**

**117. At what time of day did you begin this journey?**

**Please select from the dropdown menu. If you do not remember, select "I do not remember."**

**118. At what street/location did you begin this journey?**

Street

Locality/Town

Postcode

**119. Thinking of the place where you began your journey, why were you there?**

- Work/Business
- School/Education
- Shopping/Personal
- Social/Recreation
- Picking up/Dropping off Someone

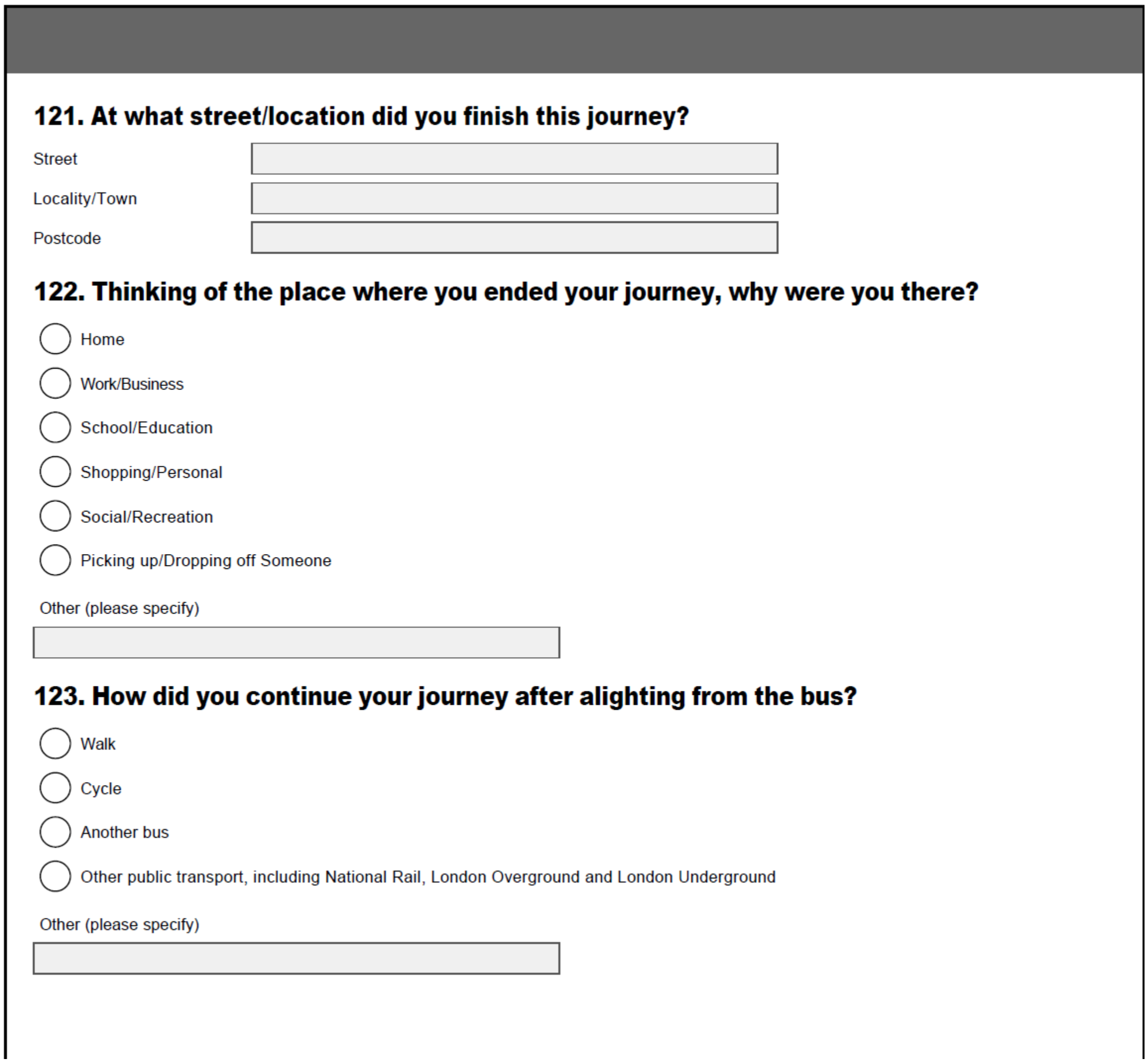
Other (please specify)

**120. How did you get to where you boarded the bus?**

- Walk
- Cycle
- Another bus
- Other public transport, including National Rail, London Overground and London Underground

Other (please specify)

**Figure A-13:** Detailed Questions About Origin of Trip from Somewhere Other Than Home



**121. At what street/location did you finish this journey?**

Street

Locality/Town

Postcode

**122. Thinking of the place where you ended your journey, why were you there?**

- Home
- Work/Business
- School/Education
- Shopping/Personal
- Social/Recreation
- Picking up/Dropping off Someone

Other (please specify)

**123. How did you continue your journey after alighting from the bus?**

- Walk
- Cycle
- Another bus
- Other public transport, including National Rail, London Overground and London Underground

Other (please specify)

**Figure A-14:** Detailed Questions About Destination of Trip from Somewhere Other Than Home

**131. How old are you?**

- ◯ 16-18
- ◯ 19-30
- ◯ 31-40
- ◯ 41-50
- ◯ 51-60
- ◯ 61-70
- ◯ Older than 70

**132. What is your gender?**

- ◯ Female
- ◯ Male

**133. What is your household income this year?**

- ◯ Less than £10,000
- ◯ £10,000 - £20,000
- ◯ £20,000 - £30,000
- ◯ £30,000 - £50,000
- ◯ More than £50,000

**134. Do you have any long-term physical or mental impairment which makes it either difficult or impossible for you to walk?**

- ◯ Yes
- ◯ No

**135. Do you have any long-term physical or mental impairment that makes it either difficult or impossible for you to stand on a bus?**

- ◯ Yes
- ◯ No

**Figure A-15:** Demographic Questions

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